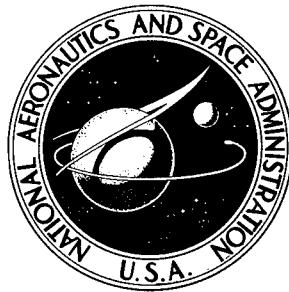


NASA TN D-7013

**NASA TECHNICAL NOTE**



**NASA TN D-7013**

**COMPUTER CODE FOR  
THE ANALYSIS OF MULTILAYERED  
FIBER COMPOSITES - USERS MANUAL**

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**19960314 029**

**NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • MARCH 1971**

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1. Report No. NASA TN D-7013	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle <b>COMPUTER CODE FOR THE ANALYSIS OF MULTILAYERED FIBER COMPOSITES - USERS MANUAL</b>		5. Report Date <b>March 1971</b>	
		6. Performing Organization Code	
7. Author(s) <b>Christos C. Chamis</b>		8. Performing Organization Report No. <b>E-5611</b>	
9. Performing Organization Name and Address Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135		10. Work Unit No. <b>129-03</b>	
		11. Contract or Grant No.	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D. C. 20546		13. Type of Report and Period Covered <b>Technical Note</b>	
		14. Sponsoring Agency Code	
15. Supplementary Notes			
16. Abstract A FORTRAN IV computer code for the micromechanics, macromechanics, and laminate analysis of multilayered fiber composite structural components is described. The code can be used either individually or as a subroutine within a complex structural analysis/synthesis program. The inputs to the code are constituent materials properties, composite geometry, and loading conditions. The outputs are various properties for ply and composite; composite structural response, including bending-stretching coupling; and composite stress analysis, including comparisons with failure criteria for combined stress. The code was used successfully in the analysis and structural synthesis of flat panels, in the buckling analysis of flat panels, in multilayered composite material failure studies, and lamination residual stresses analysis.			
17. Key Words (Suggested by Author(s)) Computer code; FORTRAN IV; Multilayered composites; Boron, glass, graphite, beryllium fiber composites; Metallic, nonmetallic; Micromechanics; Macromechanics; Laminate analysis; Ply properties; Composite properties; Constitutive equations		18. Distribution Statement <b>Unclassified - unlimited</b>	
19. Security Classif. (of this report) <b>Unclassified</b>	20. Security Classif. (of this page) <b>Unclassified</b>	21. No. of Pages <b>119</b>	22. Price* <b>\$3.00</b>

\* For sale by the National Technical Information Service, Springfield, Virginia 22151

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COMPUTER CODE FOR THE ANALYSIS OF MULTILAYERED  
FIBER COMPOSITES - USERS MANUAL<sup>\*</sup>

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SUMMARY

A computer code to carry out the multilevel linear analysis required to efficiently design structural components made from multilayered fiber composites is described. The inputs to the code are constituent materials properties, some factors reflecting the fabrication process, and composite geometry. The code performs the micromechanics, macromechanics, and laminate analysis of fiber composites. The code outputs are the various ply and composite properties, composite structural response (accounting for bending-stretching coupling etc.), and the composite stress analysis results, including the results of the combined-stress strength criteria. The code is in FORTRAN IV compiler language and can be used efficiently as a package in complex-structural analyses, finite-element methods, buckling and vibration studies, and structural syntheses. The input-output format is described extensively. Required input data to the code for various fiber-matrix composites are given. The FORTRAN compiled listing and sample trial cases are included to aid the designer or analyst in using this code. The code consists of two parts. In the first part, the mechanics to use the code are described; in the second part the equations programmed are described. The code has been used successfully in the analysis of various fiber matrix multilayered composites. It was also used (and proved to be efficient) in the structural synthesis of multilayered thornel/epoxy composite plates, in buckling studies of simply supported multilayered fiber-composite plates, and in the computation of lamination residual stresses in angle ply composites. Selection of correlation coefficients for new composite systems is described. Possible extensions for temperature-dependent properties, material nonlinearities and failure load envelopes are indicated.

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\*A part of the work described herein was supported by the Advanced Research Projects Agency, Department of Defense, through contract AF 33(615)-3110 administered by the Air Force Materials Laboratory while the author was a member of the Engineering Design Center, Case Western Reserve University, Cleveland, Ohio.

## INTRODUCTION

The importance and need of a multilevel analysis in designing structural components with multilayered fiber composites are documented in reference 1. A multilevel analysis which was found to be efficient in predicting the structural response of multilayered fiber-composites (with the constituent materials properties, the fabrication process, and the composite geometry known) is also documented in reference 1.

The multilevel analysis presented in reference 1 consists of (1) micromechanics theories for the thermoelastic properties and the stress-level limit of the single ply as functions of constituent materials properties and the particular fabrication process, (2) the combined-stress strength criterion of the single ply, and (3) multilayered composite structural response and analysis (macromechanics or laminate analyses) where the interply layer effects are taken into account. The computer code, to carry out this multilevel analysis and supplemented as noted by the additional references, is described herein.

The computer code has been programmed in FORTRAN IV and has been extensively used in the UNIVAC 1107, 1108, and IBM 7094. Since this report is to serve as a user's manual, the code is divided into two parts. In the first part, the mechanics of using the code are described with respect to program format, input-output, sample input data sheets, and tables of input data for several fiber composites. In the second part, the program is described. Sample case runs of Thorne1-50/epoxy composites with unidirectional and angle plies are included with the compiled listing in appendix B. Sample cases for bending, stretching, coupling, and lamination residual stresses are also included.

The format of the program is described in the section MAIN PROGRAM and follows the FORTRAN IV program format for the 7094. The subroutines required to carry out the various levels of analysis are described individually in their respective sections. In these subroutines, the equations programmed are given, the various alternatives for establishing certain properties (such as strain magnification factors, longitudinal compressive stress limit, and combined-stress strength criterion) are discussed, and the subroutine input-outputs and the global storage locations (common to all parts of the program) are identified. The input-output format is described in detail separately in the sections Input Ply Properties and Output. These descriptions are quite extensive so that designers and analysts with little or no programming experience as well as experienced programmers can easily use the code.

In appendix A the FORTRAN symbols are defined. The definitions include such information as in which part of the program each global variable is generated. The input data in tables IV to XIII (currently acceptable for the analysis of several fiber composites) provide for immediate use of the code. The inclusion of the compiled FORTRAN listing (appendix B) with the sample trial cases (appendix C) should further amplify the

detail descriptions. Filament and fiber are used interchangeably in the description and in the discussion. Ply, unidirectional laminate, and unidirectional composite are also used interchangeably.

It is noted that the global storage of the composite and ply properties is very important when this multilevel analysis is to be used as a subroutine package to generate structural behavior properties for structural analysis purposes.

This code has been used successfully in predicting the ply thermoelastic constants (refs. 1 to 3) in laminate analysis (boron, graphite, carbon, and glass-filament-epoxy composites; refs. 1, and 3 to 5) buckling analysis (ref. 6) and structural synthesis (ref. 1). It has also been used to calculate the lamination residual stresses in angle-ply composites (ref. 7).

Mr. Tom Delivuk, then with the same center, converted the original ALGOL CODE to the initial FORTRAN IV CODE which resulted into the CODE described herein.

#### SYMBOLS

$A_{cx}$	composite axial stiffness
$A_{cx}^R$	reduced axial stiffness
BIDE	Boolean-true if interply effects are included
$C_{cx}$	composite coupling stiffness
$C_{e1}$	string with force variables
$C_{e2}$	string with displacement variables
CSANB	Boolean-true if membrane and axial symmetry exists
$D_{cx}$	composite flexural rigidities
$D_{cx}^R$	reduced bending rigidities
$D_v$	displacement vector
$d_f$	filament equivalent diameter
$E_f, E_{cf}$	filament elastic constants
$E_l, E_{cl}$	ply elastic constants
$E_m, E_{cm}$	matrix elastic constants
$E_{f11}$ , etc.	fiber normal modulus
$E_{l11}$ , etc.	ply normal modulus

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$E_{m11}$ , etc.	matrix normal modulus
$G_{f12}$ , etc.	fiber shear modulus
$G_{\gamma 12}$ , etc.	ply shear modulus
$G_{m12}$ , etc.	matrix shear modulus
$H_j$	interply distortion energy coefficient
$H_{kc}$	array of constituents heat conductivities
$h_c$	composite heat capacity
$i, j$	index, generally ply or interply
$K_{c11}, c22, c33$	composite three-dimensional heat conductivities
$K_{cxy}, cyy, cxy$	composite two-dimensional heat conductivities
$K_{f11}$	fiber heat conductivity
$K_{\gamma 11}$	ply heat conductivity
$K_{m11}$	matrix heat conductivity
$k_f$	apparent filament volume ratio
$k_m$	apparent matrix volume ratio
$k_v$	apparent void volume ratio
$\bar{k}_f$	actual fiber volume ratio
$\bar{k}_m$	actual matrix volume ratios
$k_{fl}$	ply apparent fiber volume ratio
$k_{vl}$	ply apparent void volume ratio
$L_{sc}$	array of limiting conditions
$M_{cx}$	applied moment
$M_c \Delta T_x$	thermal moments
$m$	load condition index
$\bar{N}_{cx}$	applied membrane loads
$N_c \Delta T_x$	thermal force
$N_f$	number of fibers per end
$N_l$	number of plies
$N_{lc}$	number of load conditions
$N_{pc}$	string PROPC length

$N_{pl}$	string PROP length
$P_c$	composite properties array
$P_l$	ply properties array
$P_{cp}$	string PROPC
$P_{lp}$	string PROP main program
$Q_{f,i,p,r,s}$	indices to print out string PROP
$R$	transformation matrix
RINDV	Boolean-TRUE true if displacements are known
$S_{l11T}^{etc.}$	ply limit stresses
$t_l$	ply thickness
TLINP	FALSE if ply thickness is calculated internally
$w_{cb}$	composite local curvature changes
$x, y, z$	structural reference axes
$\alpha_c$	composite coefficient of thermal expansion
$\alpha_f$	fiber thermal coefficient of expansion
$\alpha_l$	ply thermal coefficients of expansion
$\alpha_m$	matrix thermal coefficient of expansion
$\beta_e, \beta_\epsilon$	correlation factors for ply thermoelastic properties
$\beta_h$	correlation factors for ply heat conductivities
$\beta_s$	correlation factors for ply strength
$\beta_v$	matrix strain magnification due to ply strain in the presence of voids
$\delta_l$	interply layer thickness
$\epsilon_{csx}$	reference plane membrane strains
$\epsilon_l$	ply strains
$\theta_{cs}$	angle between composite material and structural axes
$\theta_{li}, \theta_{lc}$	angle between ply material and composite axes
$\nu_{f12, etc.}$	fiber Poisson's ratio
$\nu_{l12, etc.}$	ply Poisson's ratio
$\nu_{m12, etc.}$	matrix Poisson's ratio
$\pi$	constant

$\rho_{f,m}$	filament and matrix weight density
$\sigma_l$	ply stresses
$\phi_i$	matrix strain magnification due to ply strain
1, 2, 3	material reference axes

### USERS MANUAL

The mechanics required to use this code for the analysis of multilayered fiber composites are described in this part of the manual. Here, it is assumed that the user is interested in using the code as a tool only and that he has available to him a FORTRAN IV manual. The theory on which the code is based is described in the second part of the report.

The physical representation of the code is illustrated in figure 1. The geometry of the constituents, the ply, and the composite are defined in this figure. The required input properties, correlation coefficients, and computed properties are summarized in figure 1 in symbolic form.

The physical arrangement of the code is illustrated in figure 2. The numbers given in each block of cards are for subsequent discussion and do not appear on the code. Four steps are required to use the code in the user's computer facility:

- (1) Obtain the code.
- (2) Make it operational in the user's computer facility.
- (3) Supply the input data.
- (4) Interpret the code output results.

#### Obtain the Code

The code could be obtained in cards. If this is not convenient or possible, then the cards can be punched from the compiled listing (see appendix B).

#### Make It Operational

Making the program operational requires the availability of a FORTRAN compiler in the user's computer facility, certain control cards at the beginning of the code, and the card that precedes each subroutine. Consult your computer group about these items. The control cards present in the code are only for the Lewis IBM 7044/7094 direct couple

system. Once the deck of cards has been assembled as is shown in figure 2 (except Input Data) with the proper control cards, the user is ready to compile the code in his facility. The compilation will indicate whether any additional modifications are needed. Most modifications will be minor and will usually deal with certain logical statements peculiar to each compiler. Consult your computer group for these modifications.

### Supply the Input Data

The physical arrangement of the input data cards is illustrated in figure 3. The numbers in the group of cards are for identification purposes in this description and do not appear on the cards. Details in preparing the input data cards are summarized in table I. A detailed description of these cards is given subsequently. A sample for preparing input data sheets is illustrated in table II for the Thorne-50/epoxy composite system.

Listings of input data for several composite systems appear in tables III to XII. These systems are shown graphically in figure 4. The input data for these systems can be punched from the listings, and the cards that need alterations for the specific problem can be modified accordingly.

Input data for additional composite systems may be easily prepared. This is done by selecting a related system from those in tables III to XII and modifying those entries that need modification. Table I and the section Detail Description of Input Data explain where and how each entry is read in.

After the input data have been properly assembled (as is shown in fig. 3), it is placed in its physical position (fig. 2), and the code is ready to be run for results.

### Detailed Description of Input Data

The card group numbers referred to here are given in figure 3 and table I. The sequential order of the entries in each card group is given in table I.

(1) Composite system card. - The composite system title is punched on this card. The title can be 55 characters long including blanks.

(2) Data control card. - The number of plies  $N_p$ , number of ply properties  $N_{pl}$ , number of composite properties  $N_{pc}$ , the number of fibers per end  $N_f$ , and the number of load conditions  $N_{lc}$  are entered in this card. The number of ply properties and the number of composite properties are always the same: they are  $N_{pl} = 71$  and  $N_{pc} = 54$ . The others have to be entered according to the composite system and the load conditions.

(3) Constituent materials elastic properties. - The constituent elastic properties are entered in this group of cards. The fiber properties are entered first and then the ma-

rix. Enter only extension moduli, Poisson's ratios, and zero values for shear moduli when the constituent material is isotropic. For example, in a glass/epoxy system,  $E_{f33} = E_{f22} = E_{f11}$  and  $\nu_{f23} = \nu_{f13} = \nu_{f12}$ . The shear moduli  $G_{f23} = G_{f13} = G_{f12}$  are computed internally.

(4) Correlation coefficients for ply elastic constants, expansion coefficients, and strain magnification factors. - The correlation coefficients that make theory agree with experiment are entered in this group of cards. The first entry in this group is  $\beta_m$ . It is selected so that predicted extensional moduli and Poisson's ratios correlate with measured values. The procedure for selecting  $\beta_m$  is iterative. First the code is run with  $\beta_m$  equal to some initial value. Experience has proven that  $\beta_m = 4$  is usually a good approximation for the initial value. For many systems this is also the terminal value. Next, obtain values for  $\beta_m$  greater and smaller than four, and select the proper value for  $\beta_m$  by interpolation. The aforementioned description for selecting  $\beta_m$  applies to the selection of all correlation coefficients in this code.

The second entry in this card group is  $\beta'_m$ , which is the correlation coefficient for the ply shear moduli  $G_{l12}$  and  $G_{l13}$ . The third entry is  $\beta''_m$  which is the correlation coefficient for  $G_{l13}$ . The fourth entry is  $\bar{\beta}_m$  which is the correlation coefficient for the ply thermal coefficients of expansion. The next three entries,  $\beta_\epsilon$ ,  $\beta'_\epsilon$ , and  $\beta''_\epsilon$ , are correlation coefficients for strain magnification factors  $\varphi_{\mu22}$ ,  $\varphi_{\mu12}$ , and  $\varphi_{\mu23}$ , respectively. These coefficients are entered as zeros. Experience with several composite systems has shown that the correlation coefficients  $\beta_\epsilon$  are not needed. However, they are provided for possible future use.

The coefficient  $\beta_t$  is the ratio of the thickness-to-width of the rectangle formed by an in-situ end or tow of fibers. Another way to visualize this is that  $\beta_t$  is the ratio of ply-thickness per end or tow-ply width. The value for  $\beta_t$  is obtained from electron photomicrographs or indirectly as described in reference 5. Entries 9 and 10 are entered as zeros; these fields are empty and are available for future use. Entries 11 to 14 are for the coefficients  $\gamma_m$ ; these coefficients are alternates to  $\beta_m$  and are to be used if the  $\beta_m$  coefficients do not provide the desired correlation. Note that when a  $\beta_m$  coefficient is used, the corresponding  $\gamma_m$  coefficient is entered as zero and vice versa.

Entries 15 to 17 are for the coefficients  $\gamma_\epsilon$ , which are alternates to coefficients  $\beta_\epsilon$ . Note that when a  $\beta_\epsilon$  coefficient is used the corresponding  $\gamma_\epsilon$  coefficient is zero and vice versa. The  $\gamma_\epsilon$  coefficients are entered with values of one. Entries 18 to 20 are entered as zeros. These are empty fields and are available for future use.

Experience with the code thus far has shown that all the correlation coefficients except  $\beta_t$  are approximately the same for several composite systems. (See tables III to XII.)

(5) Fiber thermal coefficients of expansion. - The coefficients  $\alpha_{f11}$ ,  $\alpha_{f22}$ , and  $\alpha_{f33}$  are entered on this card. If the fiber is isotropic, then  $\alpha_{f33} = \alpha_{f22} = \alpha_{f11}$ .

(6) Matrix thermal coefficients of expansion. - The coefficients  $\alpha_{m11}$ ,  $\alpha_{m22}$ , and  $\alpha_{m33}$  are entered in this card. When the matrix is isotropic,  $\alpha_{m33} = \alpha_{m22} = \alpha_{m11}$ .

(7) Constituent heat conductivities and heat capacities. - The first four entries in this group are for the fiber heat conductivities  $K_{f11}$ ,  $K_{f22}$ ,  $K_{f33}$ , and heat capacity  $h_{cf}$ . The next four are for the corresponding matrix properties. The next three are zero entries, and the last one is the heat conductivity  $K_v$  for air. (See card group 7 of table I.)

(8) Correlation coefficients for heat conductivities. - The four entries in this card are for the correlation coefficients  $\beta_{hv}$ ,  $\beta_{h1}$ ,  $\beta_{h2}$ , and  $\beta_{h3}$ , respectively. These coefficients are as follows:  $\beta_{kv}$  is for matrix with voids,  $\beta_{k1}$  for  $K_{l11}$ ,  $\beta_{k2}$  for  $K_{l22}$ , and  $\beta_{k3}$  for  $K_{l33}$ . They are selected as was described in  $\beta_m$  in card group (4).

(9) Constant  $\pi$ . - The value for  $\pi$  is entered in this card.

(10) Boolean for thickness. - The letter T is entered in this card if the ply thickness is supplied. The letter F is entered if the ply thickness is computed internally.

(11) Boolean for membrane and bending symmetry. - The letter T is entered in this card if the composite has both membrane and bending symmetry; otherwise the letter F is entered.

(12) Boolean for interply layer contribution. - The letter T is entered in the card if the interply layer contributions on the composite are desired; otherwise, the letter F is entered.

(13) Boolean for input displacements. - The letter T is entered in this card if the displacements are inputs; otherwise, the letter F is entered.

(14) Composite angle, constituent densities, and fiber equivalent diameter. - The composite angle (angle between composite material 1-axis and structural x-axis (fig. 5) is the first entry in this card. The fiber and matrix densities are the second and third entries. The fourth entry is the fiber equivalent diameter.

(15) Ply void volume ratio. - The void volume ratio of the plies is entered in this group of cards; the first entry is for the first ply, and the last entry is for the last ply. The bottom or the inner ply in the composite is selected as the first ply for convenience. The number of entries is equal to the number of plies in the composite. (See tables I and II.)

(16) Ply fiber volume ratio. - The ply fiber volume ratio is entered in this group of cards. The first entry is for the first ply, which is the bottom or inner ply in the composite. The last entry is for the last ply. The number of entries equals the number of plies. (See tables I and II.)

(17) Ply orientation angle. - The ply angle (measured from the composite material 1-axis to the ply material 1-axis (fig. 5)) is entered in these cards. The first entry is for the first ply which is the bottom or inner ply in the composite. The last entry is for the last ply. The number of entries equals the number of plies. (See tables I and II.)

(18) Ply thickness. - The ply thicknesses are entered in this group of cards. Two options are available. When the Boolean TLINP is F, the ply thicknesses are computed internally. In this case, the values entered do not correspond to the actual ply thicknesses. When the Boolean TLINP is T, the ply thicknesses are supplied through the input. In this case the values entered correspond to the ply actual thicknesses. The first value entered is the thickness for the bottom or inner ply of the composite. The last value entered is for the last ply and the number of values entered equals the number of plies in the composite. (See tables I and II.)

(19) Ply temperature difference. - The ply temperature difference  $\Delta T_{li}$  (the difference between cure or processing temperature and  $i^{\text{th}}$  ply temperature) is entered in this group of cards. The first entry is for the first ply (which is the bottom or inner ply), and the last entry is for the last ply. The number of entries equals the number of plies. (See tables I and II.) There are three special cases associated with the temperature difference in addition to the general case just described:

- (a) The residual stress case at room temperature where  $\Delta T_{li}$  equals the difference between cure or process temperature and room temperature.
- (b) The zero temperature effects case where  $\Delta T_{li} = 0$ .
- (c) The no residual stress case where  $\Delta T_{li}$  equals the difference between  $i^{\text{th}}$  ply temperature and room temperature.

(20) Correlation coefficients for strength. - The coefficients that correlate predicted and measured values for strength are entered in this group of cards (see table I). These coefficients are selected in the same manner as was described for  $\beta_m$  in card group (4). The first two entries are the coefficients  $\beta_{fT}$  and  $\beta_{mT}$ , which are for the ply longitudinal-tensile strength. The third entry is  $\beta_{22T}$ , which is for ply transverse-tensile strength. The fourth entry  $\beta_{12S}$  is for the ply intralaminar shear strength. The fifth entry  $\beta_{23S}$  is for the ply transverse shear strength. The sixth entry  $\beta_{\text{del}}$  is for interply delamination limit strain. Entries seven and eight are the coefficients  $K'_{l12TT}$  and  $K'_{l12TC}$ , which are for ply combined-stress strength in the tension-tension and tension-compression quadrants, respectively. Entries 9 and 10  $\beta_{fC}$  and  $\beta_{mC}$  are for the ply longitudinal compressive strength. Entry 11  $\beta_{22C}$  is for the ply transverse compressive stress. Entries 12 and 13  $a_1$  and  $a_2$  are coefficients for an alternate method to compute the ply longitudinal compressive strength (see section Subroutine GLLSC(J)). Entry 15 is entered as unity. This field is allocated for possible future use. Entries 15 and 16  $K'_{l12CT}$  and  $K'_{l12CC}$  are for ply combined-stress strength in the compression-tension and compression-compression quadrants, respectively. (See tables I and II.)

(21) Constituent strength properties. - The constituent strength properties are entered in these two cards. The six entries are, sequentially, in-situ fiber bundle strength  $S_{fT}$ , in-situ matrix compressive strengths  $S_{mC}$ , in-situ allowable matrix transverse tensile strain  $\epsilon_{mpT}$ , in-situ allowable matrix transverse compressive strain  $\epsilon_{mpC}$ ,

in-situ allowable matrix shear strain  $\epsilon_{mpS}$ , in-situ allowable matrix torsional strain  $\epsilon_{mpTor}$ . (See also tables I and II.)

(22) Membrane loads. - The membrane (in-plane) loads are entered in these cards. The first entry is the value for  $\bar{N}_{cxx}$  for the first load condition. The second entry is the value for  $\bar{N}_{cyy}$  for the second load condition, and so on until  $N_{lc}$  values for  $\bar{N}_{cxy}$  have been entered. Continue with  $N_{lc}$  values for  $\bar{N}_{cyy}$  and after that with  $N_{lc}$  values for  $\bar{N}_{cxy}$ . A total of  $3N_{lc}$  values are entered sequentially. Note that no empty fields are allowed because they will be interpreted as zero values for the load conditions by the code. Note also that zero values for  $\bar{N}_{cxx}$ ,  $\bar{N}_{cyy}$ , and  $\bar{N}_{cxy}$  have to be entered even if the displacements are read in. This is the case when RINDV equals T (TRUE). (See tables I and II.)

(23) Moments. - The local bending moments are entered in these cards. The description is analogous to that for the forces (card group (22)).

(24) Displacements. - The local reference plane strains ( $\epsilon_{csxx}$ ,  $\epsilon_{csyy}$ , and  $\epsilon_{cxy}$ ) and curvatures ( $w_{cbxx}$ ,  $w_{cbyy}$ , and  $w_{cbxy}$ ) are entered in these cards. The first six entries are for the first load condition and are entered sequentially starting with  $\epsilon_{csxx}$  and ending with  $w_{cbxy}$ . The next six entries are for the second load condition, and so on. (See tables I and II.) No blank fields are permitted in the displacement cards. Blank fields are interpreted to be zero values by the code.

Note that zero values are to be entered for the displacements even when the loads are inputs. This is the case when the Boolean (RINDV) equals T (TRUE).

### Input Ply Properties

There could be cases when the user would prefer to supply some of his own ply properties instead of using the code to compute them. The user has to provide his own formats for these cases. They are analogous to those for reading in the ply temperature difference  $\Delta T_{li}$  (card group (19)). The physical location for these statements is described in the section MAIN PROGRAM and by a comment (after DO loop 155) in the compiled listing (see appendix B).

### Output

The program output consists of printing out (1) the input data, (2) the composite three-dimension strain-stress and stress-strain relations about the structural axes, (3) the composite properties generated in array PC, (4) the composite constitutive equations about the structural axes, (5) the reduced bending and axial stiffness,

- (6) displacement-force relations, (7) the current load or displacement condition, and  
(8) the ply properties generated in array PL.

The printout of the input data is preceded by its code name. The first and second lines of printout (see table XIII for corresponding FORMATS) are

THORNEL-50/EPOXY

NL, NPL, NPC, NFPE, NLC

8 71 54 1420 1

The output of the composite three-dimensional strain-stress temperature relations and composite stress-strain relations about the structural axes are printed under the headings

#### 3-D COMPOSITE STRAIN STRESS RELATIONS - STRUCTURAL AXES

The matrices  $[E_c]_s^{-1}$  and  $\{\alpha_c\}_s$  in the equation

$$\{\epsilon_c\}_s = [E_c]_s^{-1} \{\sigma_c\} - \Delta T \{\alpha_c\}_s$$

are printed out in FORMATS 454 and 457 of subroutine GACD3.

#### 3-D STRESS STRAIN RELATIONS - STRUCTURAL AXES

The matrix  $[E_c]_s$  in

$$\{\sigma_c\}_s = [E_c]_s \{\epsilon_c\}_s$$

is printed out FORMATS 456 and 458 in GACD3. The subscript s in the preceding equations indicates that the relations are written about the structural axes. It is noted that these properties are only local to subroutine GACD3. They can be made global if needed.

The output of the composite properties, generated in array PC are printed under the heading

#### COMPOSITE PROPERTIES - VALID ONLY FOR CONSTANT TEMPERATURE THROUGH THICKNESS

LINES 1 TO 31 3-D COMPOSITE PROPERTIES ABOUT MATERIAL AXES

LINES 33 TO 54 2-D COMPOSITE PROPERTIES ABOUT STRUCTURAL AXES

Fifty-four entries are printed under this heading as follows:

PC(1)	$\rho_c$	weight density
PC(2)	$t_c$	thickness
PC(3) to PC(11)	$[E_c]$	three-dimensional stress-strain relations about material axes
PC(12) to PC(14)	$\{\alpha_c\}$	three-dimensional coefficients of expansion about material axes
PC(15) to PC(18)	$\{K_c\}, H_c$	three-dimensional heat conductivities and heat capacity along material axes
PC(19) to PC(30)	$E_{c11}, G_{c12}, \nu_{c12}$	three-dimensional constants about material axes
PC(31)	$\bar{z}$	distance to reference plane from bottom of composite
PC(32)	-----	blank
PC(33) to PC(38)	$[E_c]^{-1}$	two-dimensional stress-strain relations about structural axes
PC(39) to PC(47)	$E_{c11}, G_{c12}, \nu_{c12}$	two-dimensional elastic constants along struc- tural axes
PC(48) to PC(54)	$\{\alpha_c\}, K_c, H_c$	two-dimensional coefficients of thermal expan- sion, heat conductivities, and heat capacity along structural axes

Array PC, its corresponding string, and headings are controlled by the following formats in subroutine GOCFD2: Headings FORMATS 225, 226, and 227; and string and array PC FORMAT 320.

The output for the composite constitutive equations are printed under the heading

FORCES	FORCE DISPLACEMENT RELATIONS	DISPL	THERMAL FORCES
--------	------------------------------	-------	----------------

$$\left\{ \begin{array}{l} \{N_{cx}\} \\ \{M_{cx}\} \end{array} \right\} = \left[ \begin{array}{cc} [A_{cx}] & [C_{cx}] \\ [C_{cx}] & [D_{cx}] \end{array} \right] \left\{ \begin{array}{l} \{\epsilon_{csx}\} \\ \{w_{cb}\} \end{array} \right\} - \left\{ \begin{array}{l} \{N_{c\Delta Tx}\} \\ \{M_{c\Delta Tx}\} \end{array} \right\}$$

The elements of matrices  $A_{cx}$ ,  $C_{cx}$ ,  $N_{c\Delta Tx}$ , and  $M_{c\Delta Tx}$  are printed out. The FORMATS are 220 and 330 in GPCFD2 and STRING RESF in BLOCK DATA.

The output for the reduced bending rigidities is printed under the heading

#### REDUCED BENDING RIGIDITIES

The elements of  $D_{cx}^R$  are printed out in one line. The corresponding FORMATS are 355 and 360 in GPCFD2.

The output for the reduced axial stiffness  $A_{cx}^R$  is printed out under the heading

#### REDUCED STIFFNESS MATRIX

The corresponding FORMATS are 364 and 360 in GPCFD2.

The inverse of the constitutive equations is printed out under the heading

DISP	DISPLACEMENT FORCE RELATIONS	FORCES
------	------------------------------	--------

$$\left\{ \begin{array}{l} \{\epsilon_{cax}\} \\ \{w_{cb}\} \end{array} \right\} = \left[ \begin{array}{cc} [A_{cx}] & [C_{cx}] \\ [C_{cx}] & [D_{cx}] \end{array} \right]^{-1} \left\{ \begin{array}{l} \{N_{cx}\} \\ \{M_{cx}\} \end{array} \right\}$$

The elements of this inverse are printed out. The FORMATS are 682 and 683 in COMSA and STRING DISP in BLOCK DATA.

The output for the current load condition is printed next to the headings

FOR THIS CASE NBS(X, Y, XY-M) IS

and

FOR THIS CASE MBS (X, Y, XY-M) IS

The current values of  $\bar{N}_{cx}$ ,  $\bar{N}_{cy}$ ,  $\bar{N}_{cxy}$ ,  $\bar{M}_{cx}$ ,  $\bar{M}_{cy}$ , and  $\bar{M}_{cxy}$  are printed out under these headings. The FORMATS are 161 and 162 in the main program.

The output for the current displacement conditions is printed under the heading

FOR THIS CASE THE DISPLACEMENTS DISV (ECSXX, ECSYY, ECSXY, WCBXX, WCBYY, WCBXY) ARE

The FORMAT is 163 in MAIN PROGRAM.

The output of the ply properties generated in array PL are printed out under the heading

LAYER PROPERTIES, ROWS-PROPERTY, COLUMNS-LAYER

according to FORMAT 20 in MAIN PROGRAM.

Seventy-one entries are printed out under this heading as follows:

PL(1,I)	$k_v$	ply void content
PL(2,I)	$k_f$	ply apparent fiber content
PL(3,I)	$\bar{k}_f$	ply actual fiber content
PL(4,I)	$k_m$	ply apparent matrix content
PL(5,I)	$\bar{k}_m$	ply actual matrix content
PL(6,I)	$\rho_l$	ply weight density
PL(7,I)	$t_l$	ply layer thickness
PL(8,I)	$\delta_l$	ply and interply layer thickness
PL(9,I)	$H_j$	interply layer distortion energy coefficient
PL(10,I)	$\bar{z}$	distance from bottom of composite to ply centroid
PL(11,I)	$z_{cg}$	distance from reference plane to ply centroid
PL(12,I)	$\theta_{cs}$	angle from structural axes to composite material axes (same for all plies), fig. 2
PL(13,I)	$\theta_l$	angle from ply material axes to composite material axes (fig. 2)

PL(14,I)	$\theta_{ls}$	angle from ply material axes to composite structural axes (fig. 2)
PL(15,I) to PL(23,I)	$[E_l]^{-1}$	ply stress-strain relations
PL(24,I) to PL(26,I)	$\{\alpha_l\}$	ply thermal coefficients of expansion
PL(27,I) to PL(29,I)	$\{K_l\}$	ply heat conductivities
PL(30,I)	$H_{cl}$	ply heat capacity
PL(31,I) to PL(32,I)	$E_{l11}, \nu_{l12}, G_{l12}$	ply elastic constants
PL(43,I) to PL(48,I)	$\rho_{\mu22}, \rho_{\mu12}, \rho_{\mu13}$	ply strain magnification factors
PL(49,I)	$\rho_{\mu\text{del}}$	interply delamination factor
PL(50,I)	$\Delta T$	ply temperature
PL(51,I) to PL(60,I)	$S_{l11T}$ , etc.	ply limiting stresses
PL(61,I)	$K_{l12\alpha\beta}$	coefficient in combined-stress - strength criterion
PL(62,I)	-----	combined-stress - strength criterion
PL(63,I)	-----	interply delamination criterion
PL(64,I) to PL(69,I)	$\{\epsilon_l\}, \{\sigma_l\}$	ply applied strains and stresses
PL(70,I)	$\Delta\rho_j$	adjacent ply relative rotation
PL(70,I)	-----	Hoffman's failure criterion

The FORMAT for this output is 25 and STRING PROP in MAIN PROGRAM.

#### PROGRAM DESCRIPTION

The main program (or control program) and theoretical equations programmed in the code are described in this portion of the report. The main control program is described first, followed by descriptions of the various subroutines in their physical sequential order (fig. 2). It is assumed that the user of this portion of the code has a working knowledge of computer programming and that he is familiar with the terminology, such as, micromechanics, macromechanics, and laminate analysis of multilayered fiber composites.

The assumptions and details leading to the derivation of the equations programmed in the code are not included here. However, they are described in the references cited. It is suggested that the interested user have these references available to him.

The information provided in this portion of the code together with the compiled listing should be sufficient to enable the user to modify, implement, and extend the code according to his needs.

## MAIN PROGRAM

The main program contains the global variables, the various subroutines, the input data and format, the various program control statements, and the output. These are discussed subsequently. The flow chart of the main program is shown in figure 6.

The global variables are given in the following list (for substitution and definition, see appendix A):

Boolean	TLINP, CSANB, BIDE, RINDV
Integers	$N_l, N_{pl}, N_{pc}, N_f, N_{lc}, M, Q_i, Q_s, Q_p, Q_r, Q_f$
Real	$\theta_{cs}, \rho_f, \rho_m, d_f(E, \nu, G)_{f,m}, \pi$
Real arrays (maximum dimensions)	$K_{vl}, K_{fl}, \theta_{lc}, t_l, (1 \times 50), P_l(71 \times 50), P_c(1 \times 54), E_{cl}, E_{cf}, E_{cm}, A_{cx}, C_{cx}, D_{cx}, D_{cx}^R, A_{cx}^R (3 \times 3), \alpha_f, \alpha_m, \alpha_l, N_c \Delta T_x, M_c \Delta T_x, \epsilon_{csx}, \epsilon_{cbx} (1 \times 3), \beta_s (2 \times 8), \beta_e (2 \times 10), \beta_h (1 \times 4), L_{sc}(1 \times 6), H_{kc}(3 \times 4), \bar{M}, \bar{N}(3 \times N_{lc}), D_v(10 \times 6)$
String arrays	$C_s$ (55 spaces per field, composite system title) Read in. $P_l$ (eight spaces per field, $N_{pl}$ fields) $C_{e1}$ (six spaces per field, six fields) $C_{e2}$ (six spaces per field, six fields) $P_{cp}$ (six spaces per field, $N_{pc}$ fields)
Current dimensions	$N_l, N_{pl}, N_{pc}, N_f$
Real arrays (current dimensions)	$K_{vl}, K_{fl}, \theta_{lc}, t_l(1 \times N_l); P_l(71, N_l); P_c(N_{pc} \times 1)$

The subroutines are as follows:

INVA	inverse of an array
GLLSC	generates ply stress-limit conditions
GACD3	generates composite three-dimensional elastic and thermal properties and the two-dimensional thermal properties
BLOCK DATA	DISP (string) and RESF (string)

---

GPCFD2	generates composite two-dimensional elastic constants and constitutive equations
GPHK	generates heat conductivities of the ply
GECL	generates some ply basic properties and the ply thermoelastic constants
GSMF	generates ply strain magnification factors
COMPSCA	generates the ply strain and stress states due to applied loads and check for ply failure and interply delamination

These subroutines are described in detail in the next section. The strings of code identifier DATA are

C <sub>s</sub>	Read in according to format 4 in MAIN PROGRAM
P <sub>lp</sub>	PROP internally defined; PLHD, PLF, PLL output
C <sub>e1</sub>	RESF internally defined; FDRHD, FDRF, FDRL output
C <sub>e2</sub>	DISP internally defined; FDRF, MDRL output
P <sub>cp</sub>	PROPC internally defined; PCHD, PCF, PCL output.

The strings and arrays P<sub>lp</sub> are printed out in the main program, and C<sub>e1</sub>, C<sub>e2</sub>, and P<sub>cp</sub> are printed out in subroutine GPCFD2. All other input-outputs are operated by standard FORTRAN formats.

Input	composite system title, N <sub>l</sub> , N <sub>pl</sub> , N <sub>pc</sub> , N <sub>f</sub> , (E, ν, G) <sub>f, m</sub> , β <sub>e</sub> , α <sub>f</sub> , α <sub>m</sub> ; H <sub>kc</sub> , β <sub>h</sub> ; π; TLINP; CSANB; BIDE; RINDV; θ <sub>cs</sub> , ρ <sub>f</sub> , ρ <sub>m</sub> , d <sub>f</sub> ; k <sub>vl</sub> , k <sub>fl</sub> , θ <sub>lc</sub> , t <sub>l</sub> , ΔT <sub>l</sub> ; β <sub>s</sub> ; L <sub>sc</sub> ; $\bar{N}_{cx}$ ; $\bar{M}_{cx}$ ; D <sub>v</sub>
Control program	See portion of flow chart after CONTROL PROGRAM block in figure 6.

#### SUBROUTINE DESCRIPTION

##### Subroutine INVA(N, A, C)

This procedure computes the inverse of a square matrix A by Gauss elimination and stores it in C. The check

$$|A| \neq 0$$

is made and, if satisfied, the program continues; otherwise, the message "SINGULAR MATRIX" is displayed. The subroutine inputs are N, A order and array, respectively. The output is

$$A^{-1} \rightarrow C$$

### Subroutine GLLSC (A)

This subroutine generates the simple limit stress of the single-ply. The limit stresses for the  $i^{\text{th}}$  ply are generated from the following equations:

$$S_{l11T} = S_{fT} \left[ \beta_{fT} \bar{k}_f + \beta_{mT} \bar{k}_m \left( \frac{E_{m11}}{E_{f11}} \right) \right]$$

$$S_{l11C} = \min \left\{ S_{mc} \left( \beta_{mc} \bar{k}_m + \beta_{fc} \bar{k}_f \frac{E_{f11}}{E_{m11}} \right), \right.$$

$$\left. \left[ \frac{E_{m12}}{\left[ (1 - k_f) + k_f \left( \frac{E_{m12}}{E_{f12}} \right) \right]} \right] \times \left[ \frac{1 - 2 \left( \frac{k_v}{1 - k_f} \right) + \left( \frac{k_v}{1 - k_f} \right)^2}{1 + \left( \frac{k_v}{1 - k_f} \right)} \right] \right\}$$

The second part of the preceding equation was proposed in reference 8.

$$S_{l11CD} = a_1 S_{l12S} + a_2$$

$$S_{l22T} = \beta_{22T} \left( \frac{\epsilon_{mpT}}{\beta_v \varphi_{\mu 22}} \right) E_{l22}$$

$$S_{l22C} = \beta_{22C} \left( \frac{\epsilon_{mpC}}{\beta_v \varphi_{\mu 22}} \right) E_{l22}$$

$$S_{l13S} = S_{l12S} = \beta_{12S} \left( \frac{\epsilon_{mpS}}{\beta_v \varphi_{\mu 12}} \right) G_{l12}$$

$$S_{l23S} = \beta_{23S} \left( \frac{\epsilon_{mpS}}{\beta_v \varphi_{\mu 23}} \right) G_{l23}$$

The transverse shear limiting conditions for the  $j^{\text{th}}$  interply layer are not generated here. However, provisions for them are made in PL(58,I) and PL(59,I) (where I denotes the column (ply) index). The limiting stresses  $S_{l11T} - S_{l23S}$  and  $\varphi_{\mu \text{del}}$  are stored in PL(51,I) to PL(57,I) and in PL(60,I), respectively. The required input to the procedure is global and is stored in the following arrays:

$$\text{LSC} = [S_{ft}, S_{mC}, \epsilon_{mpT}, \epsilon_{mpC}, \epsilon_{mpS}, \epsilon_{mptor}]$$

$$\text{BET} = \begin{bmatrix} \beta_{fT}, \beta_{mT}, \beta_{22T}, \beta_{12S}, \beta_{23S}, \beta_{de1}, K'_{l12TT} K'_{l12TC} \\ \beta_{fC}, \beta_{mC}, \beta_{22C}, a_1, a_2, \beta_S, K'_{l12CT} K'_{l12CC} \end{bmatrix}$$

The fiber and matrix moduli are input data. The ply moduli  $E_{l22}$ ,  $G_{l12}$ ,  $G_{l23}$  and the products of  $\beta_v \varphi_{\mu}$  are stored in PL(32,I), PL(36,I), PL(34,I), and PL(43,I) to PL(48,I), respectively. The ply moduli and the strain magnification factors are generated in subroutines GECL and GSMF.

### Subroutine GACD3(C)

This subroutine generates the three-dimensional thermoelastic properties of the composite about its structural (x, y, z) and material (1, 2, 3) axes. The angle  $\theta$  is measured from x of the structural axes system. (See fig. 5.) In figure 5 replace xx etc. by 11 etc., and measure  $\theta$  from the material axes for properties about the material axes. These composite properties are generated from the following equations:

$$[E_c] = \frac{1}{t_c} \left[ \sum_{i=1}^{N_l} (z_{li+1} - z_{li}) [R_{li}]^T [E_{li}] [R_{li}] + \sum_{j=1}^{N_l-1} H_j [S_j] \right]$$

$$\{\alpha_c\} = \frac{1}{t_c} [E_c] \sum_{i=1}^{N_l} (z_{li+1} - z_{li}) [R_{li}]^T [E_{li}] \{\alpha_{li}\}$$

The arrays  $\{\alpha_c\}$  and  $\{\alpha_{li}\}$  in the preceding equations are given by

$$\{\alpha_c\} = [\alpha_{cxx} \alpha_{cyy} \alpha_{czz} \alpha_{cyz} \alpha_{czx} \alpha_{cxy}]^T$$

and

$$\{\alpha_{li}\} = [\alpha_{l11} \alpha_{l22} \alpha_{l33} 0 0 0]^T$$

For all practical purposes the two-dimensional thermal coefficients of expansion about the composite structural axes are the same as  $\alpha_{cyy}$ ,  $\alpha_{cyy}$ , and  $\alpha_{cxy}$  in the array  $\{\alpha_c\}$  for the three-dimensional case.

The matrices  $[E_c]$ ,  $[E_{li}]$ ,  $[R_{li}]$ , and  $[S_j]$  are given by

$$[E_c]^{-1} = \begin{bmatrix} \frac{1}{E_{c11}} & -\frac{\nu_{c21}}{E_{c22}} & -\frac{\nu_{c31}}{E_{c33}} & 0 & 0 & 0 \\ -\frac{\nu_{c12}}{E_{c11}} & \frac{1}{E_{c22}} & -\frac{\nu_{c32}}{E_{c33}} & 0 & 0 & 0 \\ -\frac{\nu_{c13}}{E_{c11}} & -\frac{\nu_{c23}}{E_{c22}} & \frac{1}{E_{c33}} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{E_{c23}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{E_{c31}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{E_{c12}} \end{bmatrix}$$

Note that for the case of an anisotropic material, the elements (1,6) (2,6) (3,6) (4,5), and their symmetric parts will not be zero.

$$[E_{li}]^{-1} = \begin{bmatrix} \frac{1}{E_{l11}} & -\frac{\nu_{l21}}{E_{l22}} & -\frac{\nu_{l31}}{E_{l33}} & 0 & 0 & 0 \\ -\frac{\nu_{l12}}{E_{l11}} & \frac{1}{E_{l22}} & -\frac{\nu_{l32}}{E_{l33}} & 0 & 0 & 0 \\ -\frac{\nu_{l13}}{E_{l11}} & -\frac{\nu_{l23}}{E_{l22}} & \frac{1}{E_{l33}} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{E_{l23}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{E_{l31}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{E_{l12}} \end{bmatrix}_i$$

$$[R_{li}] = \begin{bmatrix} \cos^2 \theta & \sin^2 \theta & 0 & 0 & 0 & \frac{1}{2} \sin 2\theta \\ \sin^2 \theta & \cos^2 \theta & 0 & 0 & 0 & -\frac{1}{2} \sin 2\theta \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & \cos \theta & \sin \theta & 0 \\ 0 & 0 & 0 & -\sin \theta & \cos \theta & 0 \\ -\sin 2\theta & \sin 2\theta & 0 & 0 & 0 & \cos 2\theta \end{bmatrix}$$

where  $\theta = \theta_{li}$  for properties about the composite material and  $\theta = \theta_{li} + \theta_{cs}$  for properties about the composite structural axes (see fig. 5).

$$[S_j] = \frac{1}{4} \begin{bmatrix} (\sin 2\theta_i - \sin 2\theta_{i-1})^2 & -(\sin 2\theta_i - \sin 2\theta_{i-1})^2 & 0 & 0 & 0 & [ -(\sin 2\theta_i - \sin 2\theta_{i-1}) \\ & & & & & \times (\cos 2\theta_i - \cos 2\theta_{i-1}) ] \\ -(\sin 2\theta_i - \sin 2\theta_{i-1})^2 & (\sin 2\theta_i - \sin 2\theta_{i-1})^2 & 0 & 0 & 0 & [ (\sin 2\theta_i - \sin 2\theta_{i-1}) \\ & & & & & \times (\cos 2\theta_i - \cos 2\theta_{i-1}) ] \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ -[(\sin 2\theta_i - \sin 2\theta_{i-1}) & [(\sin 2\theta_i - \sin 2\theta_{i-1}) & 0 & 0 & 0 & (\cos 2\theta_i - \cos 2\theta_{i-1})^2 \\ & \times (\cos 2\theta_i - \cos 2\theta_{i-1})] & & & & \times (\cos 2\theta_i - \cos 2\theta_{i-1})] \end{bmatrix}$$

where  $i > 1$  and denotes the ply index. The angles  $\theta_i$  and  $\theta_{i-1}$  (fig. 5) are given by

$$\theta_i = \theta_{li} + \theta_{cs}$$

$$\theta_{i-1} = \theta_{li-1} + \theta_{cs}$$

The composite heat capacity is the same for both the three- and the two-dimensional cases. It is given by

$$h_c = \frac{1}{t_c} \sum_{i=1}^{N_l} h_{li} t_{li}$$

and  $t_c$  is given by

$$t_c = \sum_{i=1}^{N_l} t_{li}$$

The composite three-dimensional heat conductivities along the composite material axes, assuming an orthotropic composite, are given by

$$K_{c11} = \frac{1}{t_c} \sum_{i=1}^{N_l} t_{li} \left( K_{l11} \cos^2 \theta_l + K_{l22} \sin^2 \theta_l \right)_i$$

$$K_{c22} = \frac{1}{t_c} \sum_{i=1}^{N_l} t_{li} \left( K_{l11} \sin^2 \theta_l + K_{l22} \cos^2 \theta_l \right)_i$$

$$\frac{1}{K_{c33}} = \frac{1}{t_c} \sum_{i=1}^{N_l} \left( \frac{t_l}{K_{l33}} \right)_i$$

The angle  $\theta_l$  is measured from the material axes (fig. 5).

The composite two-dimensional heat conductivities along the composite structural axes are given by (see ref. 9 for the transformation equations)

$$K_{cxx} = \frac{1}{t_c} \sum_{i=1}^{N_l} t_{li} \left( K_{l11} \cos^2 \theta + K_{l22} \sin^2 \theta \right)_i$$

$$K_{cyy} = \frac{1}{t_c} \sum_{i=1}^{N_l} t_{li} \left( K_{l11} \sin^2 \theta + K_{l22} \cos^2 \theta \right)_i$$

$$K_{cyx} = K_{cxy} = \frac{1}{t_c} \sum_{i=1}^{N_l} t_{li} \left( K_{l22} - K_{l11} \right)_i \sin 2\theta_i$$

$$K_{czz} = K_{c33}$$

The angle  $\theta$  in the last set of equations is measured from the composite structural axes and is equal to  $\theta_{cs} + \theta_l$ . The inputs to the subroutine are  $N_l$ ,  $z_{li+1}$ ,  $z_{li}$ ,  $\theta_{cs}$ ,  $\theta_{li}$ ,  $[E_i]$ ,  $H_j$ ,  $\{\alpha_{li}\}$ ,  $h_{li}$ , and  $\{K_{li}\}$  which are all global. The variable  $N_l$  is input data. The remaining quantities are either generated or are transferred from information stored in PL(11,I), PL(13,I), PL(15-23,I), PL(8,I), PL(24,I) to PL(26,I) PL(30,I), and PL(27,I) PL(29,I). The outputs are  $t_c$  and the arrays are  $[E_c]^{-1}$ ,  $\{\alpha_c\}$ ,  $[E_c]$ ,  $h_c$ , and  $\{K_c\}$ . The composite thickness  $t_c$  is stored in PC(2). The arrays  $[E_c]^{-1}$ ,  $\{\alpha_c\}$ , and  $[E_c]$  for both composite material and structural axes are printed out under the headings:

### 3-D COMPOSITE STRAIN STRESS TEMPERATURE RELATIONS - STRUCTURAL AXES

and

### 3-D COMPOSITE STRESS STRAIN RELATIONS - STRUCTURAL AXES

The composite material axes properties  $[E_c]$  and  $\{\alpha_c\}$  are stored in PC(3) to PC(14) as global variables. The corresponding moduli are stored in PC(19) to PC(30). The three-dimensional heat conductivities and heat capacity along the material axes are stored in PC(15) to PC(18). The two-dimensional thermal coefficients of expansion along the structural axes are stored in PC(48) to PC(50). The two-dimensional heat conductivities and heat capacity along the structural axes are stored in PC(51) to PC(54). Note that the heat capacity is a scalar quantity and is independent of the reference axes. Therefore, PC(54) equals PC(18).

### Subroutine BLOCK DATA

In this block, the strings  $C_{e1}$  and  $C_{e2}$  which are printed out with the composite constitutive equations are defined. The string  $C_{e1}$  contains the resultant force notation  $N_{cx}$ ,  $N_{cy}$ ,  $N_{cxy}$ ,  $M_{cx}$ ,  $M_{cy}$ , and  $M_{cxy}$ . The string  $C_{e2}$  contains the notation for the corresponding displacements.

### Subroutine GPCFD2 (RESF, DISP, PROPC)

This subroutine generates the required section properties and the force-deformation-temperature relations for a two-dimensional multilayered composite. It also generates the plane-stress elastic constants for the composite. The force-deformation-temperature relations generated in this procedure are defined in the following equation:

$$\begin{Bmatrix} \{N_{cx}\} \\ \{M_{cx}\} \end{Bmatrix} = \begin{bmatrix} [A_{cx}] & | & [C_{cx}] \\ \hline [C_{cx}] & | & [D_{cx}] \end{bmatrix} \begin{Bmatrix} \{\epsilon_{csx}\} \\ \{w_{cbx}\} \end{Bmatrix} - \begin{Bmatrix} \{N_c \Delta T_x\} \\ \{M_c \Delta T_x\} \end{Bmatrix}$$

The generic equations for the elements in the arrays  $[A_{cx}]$ ,  $[C_{cx}]$ ,  $[D_{cx}]$ ,  $\{N_c \Delta T_x\}$ , and  $\{M_c \Delta T_x\}$  are

$$[A_{cx}] = \sum_{i=1}^{N_l} \Delta T_{li} (z_{li+1} - z_{li}) [R_{li}]^T [E_{li}]^{-1} [R_{li}] + \sum_{j=1}^{N_l-1} H_j [S_j]$$

$$[C_{cx}] = \sum_{i=1}^{N_l} \Delta T_{li} (z_{li+1}^2 - z_{li}^2) [R_{li}]^T [E_{li}]^{-1} [R_{li}] + \sum_{j=1}^{N_l-1} z_{rpj} H_j [S_j]$$

$$[D_{cx}] = \sum_{i=1}^{N_l} \Delta T_{li} (z_{li+1}^3 - z_{li}^3) [R_{li}]^T [E_{li}]^{-1} [R_{li}] + \sum_{j=1}^{N_l-1} z_{rpj}^2 H_j [S_j]$$

$$\{N_c \Delta T_x\} = \sum_{i=1}^{N_l} \Delta T_{li} (z_{li+1} - z_{li}) [R_{li}] [E_{li}]^{-1} \{\alpha_{li}\}$$

$$\{M_c \Delta T_x\} = \sum_{i=1}^{N_l} \Delta T_{li} (z_{li+1}^2 - z_{li}^2) [R_{li}]^T [E_{li}]^{-1} \{\alpha_{li}\}$$

The arrays  $\{\alpha_{li}\}$ ,  $[R_{li}]$ ,  $[E_{li}]$ , and  $[S_j]$  are

$$\{\alpha_{li}\} = [\alpha_{11} \quad \alpha_{22} \quad 0]_i^T$$

$$[R_{li}] = \begin{bmatrix} \cos^2 \theta & \sin^2 \theta & \frac{1}{2} \sin 2\theta \\ \sin^2 \theta & \cos^2 \theta & -\frac{1}{2} \sin 2\theta \\ -\sin 2\theta & \sin 2\theta & \cos 2\theta \end{bmatrix}_i$$

$$[E_{li}] = \begin{bmatrix} \frac{1}{E_{l11}} & -\frac{\nu_{l21}}{E_{l22}} & 0 \\ -\frac{\nu_{l12}}{E_{l11}} & \frac{1}{E_{l22}} & 0 \\ 0 & 0 & \frac{1}{G_{l12}} \end{bmatrix}_i$$

$$S_{j22} = S_{j11} = \frac{1}{4} (\sin 2\theta_i - \sin 2\theta_{i-1})^2$$

$$S_{j21} = S_{j12} = -S_{j11}$$

$$S_{j32} = S_{j23} = \frac{1}{4} (\sin 2\theta_i - \sin 2\theta_{i-1})(\cos 2\theta_i - \cos 2\theta_{i-1})$$

$$S_{j31} = S_{j13} = -S_{j23}$$

$$S_{j33} = \frac{1}{4} (\cos 2\theta_i - \cos 2\theta_{i-1})^2$$

Here  $\theta_i$  equals the  $\theta_{cs} + \theta_l$  in figure 5. The reduced bending rigidities (ref. 6) are generated in this procedure according to the equation

$$D_{cx}^R = [D_{cx} - C_{cx} A_{cx}^{-1} C_{cx}]$$

The reduced axial stiffnesses are generated in the procedure according to the equation

$$A_{cx}^R = [A_{cx} - C_{cx} D_{cx}^{-1} C_{cx}]$$

The two-dimensional composite elastic constants are generated from the following equation (assuming  $\Delta T_{li} = \Delta T$  for  $i = 1(1)N_l$ ):

$$[E_{cx}]^{-1} = \frac{1}{t_c} \left\langle \sum_{i=1}^{N_l} (z_{l_{i+1}} - z_{l_i}) [R_{l_i}]^T [E_{l_i}]^{-1} [R_{l_i}] + \sum_{j=1}^{N_l-1} H_j [S_j] \right\rangle$$

where

$$t_c = \sum_{i=1}^{N_l} t_{l_i}$$

The inputs to this subroutine are  $t_{l_i}$ ,  $\Delta T_{l_i}$ ,  $\theta_i$  (relative to composite structural axes),  $H_j$ , and the ply elastic constants. These quantities are global and are located, respectively, in PL(7,I), (50,I), (14,I), (9,I), and (31,I) to (42,I). The arrays  $[R_{l_i}]^T [E_{l_i}]^{-1}$ ,  $[R_{l_i}]$ , and  $[S_j]$  and the dimensions  $z_{l_i}$  are generated within subroutine.

The outputs are the force-deformation-temperature relations, which are stored in the global arrays  $ACX = A_{cx}$ ,  $RAC = A_{cx}^R$ ,  $CPC = C_{cx}$ ,  $FLX = D_{cx}$ ,  $RDC = D_{cx}^R$ ,  $NSDT = N_c \Delta T_x$ , and  $MSDT = M_c \Delta T_x$ . These are printed out under the heading

**FORCES FORCE DISPLACEMENT RELATIONS DISPL THERMAL FORCES**

The reduced bending rigidities are printed out under the heading

**REDUCED BENDING RIGIDITIES**

The reduced axial stiffnesses are printed out under the heading

**REDUCED STIFFNESS MATRIX**

The inverse of the constitutive equations

$$\begin{bmatrix} [A_{cx}] & | & [C_{cx}] \\ \hline \hline [C_{cx}] & | & [D_{cx}] \end{bmatrix}^{-1}$$

are printed out under the heading

**DISP DISPLACEMENT FORCE RELATIONS FORCES**

The distances  $\bar{z}_c$ ,  $\bar{z}_{li}$ ,  $z_{li}$  are stored, respectively, in PC(31), PL(10,I), and PL(11,I). The two-dimensional composite stress-strain relations is stored in PC(33) to PC(38) and the two-dimensional composite moduli and Poisson's ratio are stored in PC(39) to PC(47). The two-dimensional thermal properties are stored in PC(48) to PC(54) as is described in the section Subroutine GACD3.

#### Subroutine GPH (CF, CM, R, Q, CP)

This subroutine is used to calculate the ply conductivities  $K_{l22}$  and  $K_{l33}$ . The specific equation programmed in this subroutine is

$$K_{l\alpha\alpha} = \bar{K}_{m\alpha\alpha} \left[ 1 - \beta_{k\alpha} \sqrt{\bar{k}_f} + \frac{1}{\frac{1}{\beta_{k\alpha}\sqrt{\bar{k}_f}} - \left( 1 - \frac{\bar{K}_{m\alpha\alpha}}{K_{f\alpha\alpha}} \right)} \right]$$

where  $\alpha$  takes the values 2 and 3. The subroutine is called from subroutine GECL. The subroutine input variables CF, CM, R, and Q and the output variable CP are defined in the call statement in GECL. They denote, respectively, fiber conductivity  $K_{f\alpha\alpha}$ , matrix conductivity  $\bar{K}_{m\alpha\alpha}$  (modified for void effects), actual fiber volume ratio  $\bar{k}_f$ , correlation factor  $\beta_{k\alpha}$ , and the computed conductivity  $K_{l\alpha\alpha}$  which is the subroutine output.

#### Subroutine GECL (KV, KF)

The thermoelastic properties of the single ply are generated in this procedure. In addition the actual fiber and matrix volume content, the ply thickness, density, and the interfiber spacing are generated. The equations programmed to generate basic ply properties are

$$\bar{k}_f = (1.0 - k_v)k_f$$

$$\bar{k}_m = (1.0 - k_v)(1 - k_f)$$

$$\rho_l = \rho_f \bar{k}_f + \rho_m \bar{k}_m$$

$$t_l = \begin{cases} (\pi N_f / 4\beta_t \bar{k}_f)^{1/2} d_f & \text{if Boolean TLINP = F(FALSE)} \\ \text{Read in value if Boolean TLINP = T(TRUE)} \end{cases}$$

$$\delta_l = \left[ \left( \frac{\pi}{4\bar{k}_f} \right)^{1/2} - 1 \right] d_f$$

where  $k_v$  and  $k_f$  are read in globally. The equations programmed to generate the extensional moduli and the thermal coefficients of expansion are

$$[E_l] = [C_{fl}]^T [E_f] [C_{fl}] \bar{k}_f + [C_{ml}]^T [E_m] [C_{ml}] \bar{k}_m$$

and

$$\{\alpha_l\} = [C_{fl}]^T \{\alpha_f\} \bar{k}_f + [C_m]^T \{\alpha_m\} \bar{k}_m$$

The arrays in the last two equations are given by

$$[E_{l,f,m}] = \begin{bmatrix} \frac{1}{E_{l11}} & -\frac{\nu_{l21}}{E_{l22}} & -\frac{\nu_{l31}}{E_{l33}} \\ -\frac{\nu_{l12}}{E_{l11}} & \frac{1}{E_{l22}} & -\frac{\nu_{l32}}{E_{l33}} \\ -\frac{\nu_{l13}}{E_{l11}} & -\frac{\nu_{l23}}{E_{l22}} & \frac{1}{E_{l33}} \end{bmatrix}_{l,f,m}$$

and

$$\{\alpha_{l,f,m}\} = [\alpha_1, \alpha_2, \alpha_3]_{l,f,m}$$

The arrays  $[E_l]$ ,  $[E_f]$ , and  $[E_m]$  are generated locally in the arrays ECL, ECF, and ECM, respectively. The arrays  $[C_{fl}]$  and  $[C_{ml}]$  and the constants in them are given by

$$[C_{fl}] = \begin{bmatrix} \frac{1}{AE_{m11}\bar{k}_m} & \frac{1}{A} \left( \frac{\nu_{f21}}{C_f E_{f22}} - \frac{\nu_{m21}}{C_m E_{m22}} \right) & \frac{1}{A} \left( \frac{\nu_{f31}}{C_f E_{f33}} - \frac{\nu_{m31}}{C_m E_{m33}} \right) \\ 0 & \frac{1}{C_f} & 0 \\ 0 & 0 & \frac{1}{C_f} \end{bmatrix}$$

and

$$[C_{ml}] = \begin{bmatrix} \frac{1}{BE_{f11}\bar{k}_f} & \frac{1}{B} \left( \frac{\nu_{m21}}{C_m E_{m22}} - \frac{\nu_{f21}}{C_f E_{f22}} \right) & \frac{1}{B} \left( \frac{\nu_{m31}}{C_m E_{m33}} - \frac{\nu_{f31}}{C_f E_{f33}} \right) \\ 0 & \frac{1}{C_m} & 0 \\ 0 & 0 & \frac{1}{C_m} \end{bmatrix}$$

where

$$A = \left( \frac{1}{E_{f11}} + \frac{\bar{k}_m}{E_{m11}} \bar{k}_f \right)$$

$$B = \left( \frac{1}{E_{m11}} + \frac{\bar{k}}{E_{f11}} \bar{k}_m \right)$$

$$C_f = \left( \frac{\bar{k}_f}{k_f} \right) \beta_f$$

$$C_m = \left( \frac{\bar{k}_m}{k_m} \right) \beta_m = (1 - k_v) \beta_m$$

$$\beta_f = 1.0$$

$$\beta_m = \begin{cases} \left(\frac{1.0}{k_m}\right)^{1/VCF(1,1)} & \text{if } VCF(1,1) \neq 0 \\ VCF(2,1) & \text{if } VCF(1,1) = 0 \end{cases}$$

The variables  $VCF(1,1)$  and  $VCF(2,1)$  are empirical (adjustment) factors and are read in. Here and subsequently, the elements in the array  $VCF$  constitute experiment-theory correlation (semiempirical) factors and are selected so that the predicted and experimental results for a particular fiber-matrix system from a particular fabrication process are in good agreement. The variable  $\beta_f$  could be selected to be different from unity if additional adjustment is needed.

The elements in the arrays  $[\tilde{C}_{f_l}]$  and  $[\tilde{C}_{m_l}]$  are generated by substituting

$$\tilde{\beta}_f = 1.0$$

$$\tilde{\beta}_m = \begin{cases} \left(\frac{1.0}{k_m}\right)^{1/VCF(1,4)} & \text{if } VCF(1,4) \neq 0 \\ VCF(2,4) & \text{if } VCF(1,4) = 0 \end{cases}$$

The equations programmed to generate the shear moduli are

$$G_{l12} = \frac{G_{m12}}{\frac{G_{m12}}{C_f'^2 G_{f12}} \bar{k}_f + \frac{\bar{k}_m}{C_m'^2}}$$

$$G_{l13} = \frac{G_{m13}}{\frac{G_{m13}}{C_f'^2 G_{f13}} \bar{k}_f + \frac{\bar{k}_m}{C_m'^2}}$$

and

$$G_{l23} = \frac{G_{m23}}{\frac{G_{m23}}{C_m''^2 G_{f23}} \bar{k}_f + \frac{\bar{k}_m}{C_m''^2}}$$

where

$$C_f' = \left( \frac{\bar{k}_f}{k_f} \right) \beta_f'$$

$$C_m' = \left( \frac{\bar{k}_m}{k_m} \right) \beta_m'$$

$$C_f'' = \left( \frac{\bar{k}_f}{k_f} \right) \beta_f''$$

and

$$C_m'' = \left( \frac{\bar{k}_m}{k_m} \right) \beta_m''$$

The variables  $\beta_f'$ ,  $\beta_m'$ ,  $\beta_f''$ , and  $\beta_m''$ , respectively, are

$$\beta_f' = 1.0$$

$$\beta_m' = \begin{cases} \left( \frac{1.0}{k_m} \right)^{1/VCF(1,2)} & \text{if } VCF(1,2) \neq 0 \\ VCF(2,2) & \text{if } VCF(2,2) = 0 \end{cases}$$

$$\beta_f'' = 1.0$$

$$\beta_m'' = \begin{cases} \left(\frac{1.0}{k_m}\right)^{1/VCF(1, 3)} & \text{if } VCF(1, 3) \neq 0 \\ VCF(2, 3) & \text{if } VCF(2, 3) = 0 \end{cases}$$

The equations programmed for the ply heat capacity and the ply heat conductivities are

$$H_{cli} = \frac{1}{\rho_{li}} \left( H_{cf} \rho_f \bar{k}_f + H_{cm} \rho_m \bar{k}_m \right)$$

$$\bar{K}_{m\alpha\alpha} = K_{m\alpha\alpha} \left[ \frac{2\beta_{kv} K_{m\alpha\alpha} + K_v - 2k_v(K_{m\alpha\alpha} - K_v)}{2K_{m\alpha\alpha} + K_v - k_v(K_{m\alpha\alpha} - K_v)} \right]$$

and

$$K_{l11} = \beta_{k1} \bar{k}_f K_{f11} + k_m \bar{K}_{m11}$$

The subscript  $\alpha$  takes the values (1, 2, and 3). The remaining variables are read in globally in the arrays

$$BTA = (\beta_{kv}, \beta_{k1}, \beta_{k2}, \beta_{k3})$$

and

$$CHK = \begin{bmatrix} K_{f11} & K_{f22} & K_{f33} & H_{cf} \\ K_{m11} & K_{m22} & K_{m33} & H_{cm} \\ 0 & 0 & 0 & K_v \end{bmatrix}$$

The small subroutine GPHK(CF, CM, R, Q, CP) preceding subroutine GECL is used for programming convenience to compute the variables  $K_{l22}$  and  $K_{l33}$ .

Inputs to subroutine GECL are the fiber and matrix material properties and the correlation factors. These properties are read in globally and are ( $E$ ,  $\nu$ ,  $G$ ,  $\rho$ ,  $H_c$ ,  $K$ ,  $\alpha_f, m$ ,  $N_f$ ,  $d_f$ ,  $VCF$ ,  $BTA$ ,  $TLINP$ , and  $(k_v, k_f)_i$  (where  $i = 1(1)N_l$  and  $N_l$  is the number of layers). For the corresponding code identifiers, see appendix A.

The outputs of subroutine GECL are the basic ply properties ( $\bar{k}_f$ ,  $\bar{k}_m$ ,  $\rho_l$ ,  $t_l$  (if TLINP = FALSE), and  $\delta_l$ ) which are stored in PL(3,I) and in PL(5,I) to PL(8,I); the ply stress-strain relations, which are stored in PL(15,I) to PL(23,I); the ply thermal coefficients of expansion, heat conductivities, and heat capacity, which are stored in PL(24,I) to PL(30,I), and the ply moduli and Poisson's ratios, which are stored in PL(31,I) to PL(42,I).

#### Subroutine GSMF(SL11, SL22, SL12, SL23, KV, KF, J)

The strain magnification factors from which the ply unidirectional limiting stresses are constructed are generated in this subroutine. These factors are  $\varphi_{\mu 22}$ ,  $\varphi_{\mu 12}$ , and  $\varphi_{\mu 23}$  for constructing  $S_{l22}$ ,  $S_{l12}$ , and  $S_{l23}$ , respectively.

Three methods are employed to compute  $\varphi_{\mu 22}$ : Kies's two-dimensional, Daniel's indirect, and Kies's one-dimensional method. Filament and matrix orthotropicity and the effects of voids are included in all of these methods as is described in reference 1. Kies's two-dimensional method is selected to construct  $S_{l22}$  in the current program. However, either of the other methods and even new ones (as they become available) could be chosen if, at some future date, they are found to be more appropriate. In addition, optional degrees of freedom for adjusting these factors can be read in globally. The options are given with the appropriate equation. The input and output subroutine information is discussed at the end of this section.

The equations programmed in this subroutine are

$$\beta_v = \frac{1.0}{\left[ 1 - \left( \frac{4k_v}{\pi k_m} \right)^{1/2} \right]}$$

$$\bar{k}_f = (1 - k_v)k_f$$

$$\bar{k}_m = (1 - k_v)(1 - k_f)$$

$$C_{f\varphi} = \frac{\bar{k}_f}{k_f}$$

and

$$C_{m\varphi} = \frac{\bar{k}_m}{(1 - k_f)}$$

Strain magnification factor  $\varphi_{\mu 22}$ . - The three methods used to compute the strain magnification factor  $\varphi_{\mu 22}$  are given in the following:

(1) Kies's two-dimensional method:

$$p = \begin{cases} \bar{k}_f (1.0/\beta_\epsilon) & \text{if } \beta_\epsilon \neq 0 \\ \left(\frac{4\bar{k}_f}{\pi}\right)^{1/2} \gamma_\epsilon & \text{if } \beta_\epsilon = 0 \end{cases}$$

$$\bar{A} = \frac{(1 - \nu_{f12} \nu_{f21}) C_{m\varphi} E_{m22}}{(1 - \nu_{m12} \nu_{m21}) C_{f\varphi} E_{f22}}$$

$$\bar{B} = \nu_{m12} \bar{A}$$

$$\frac{\epsilon_{m22}}{\epsilon_{l22}} = \left[ \frac{1}{1 + p(A - 1)} \right] \left\{ \frac{1}{E_{l22}} \left[ 1 - \nu_{l21} p(\nu_{f12} - \bar{B}) \right] \sigma_{l22} + \frac{1}{E_{l11}} \left[ p(\nu_{f12} - \bar{B}) - \nu_{l12} \right] \sigma_{l11} \right\}$$

$$\epsilon_{l22} = \frac{\sigma_{l22}}{E_{l22}} - \frac{\nu_{l12} \sigma_{l11}}{E_{l11}}$$

$$\varphi_{\mu 22} = \begin{cases} \frac{\epsilon_{m22}}{\epsilon_{l22}} & \text{if } \frac{\epsilon_{m22}}{\epsilon_{l22}} > 1.0 \\ 1.0 & \text{if } \frac{\epsilon_{m22}}{\epsilon_{l22}} \leq 1.0 \end{cases}$$

$$\varphi_{\mu 22} \beta_v \rightarrow PL(45, J)$$

(2) Daniel's indirect method:

$$\varphi_{\mu 22} = k_\sigma \left(1 - \nu_{m23}^2\right) \frac{E_{l22}}{E_{m22}}$$

$$k_\sigma = 0.83 \left[ \left( \frac{\pi}{\bar{k}_f} \right)^2 - 2 \right]^2 - 1.35 \left[ \left( \frac{\pi}{\bar{k}_f} \right)^{1/2} - 2 \right] + 1.78$$

$$0.35 \leq \bar{k}_f \leq 0.75$$

$$\varphi_{\mu 22} \beta_v \rightarrow PL(44, J)$$

(3) Kies's one-dimensional method:

$$\varphi_{\mu 22} = \frac{1}{1 - p \left( 1 - \frac{C_m \varphi E_{m22}}{C_f \varphi E_{f22}} \right)}$$

$$\varphi_{\mu 22} \beta_v \rightarrow PL(43, J)$$

Note that PL(46, J) is blank for any other method that might be of interest.

Strain magnification factor  $\varphi_{\mu 12}$  -

$$p = \begin{cases} \frac{1}{\bar{k}_f} 1.0/\beta'_\epsilon & \text{if } \beta'_\epsilon \neq 0 \\ \left( \frac{4\bar{k}_f}{\pi} \right)^{1/2} \gamma'_\epsilon & \text{if } \beta'_\epsilon = 0 \end{cases}$$

$$\varphi_{\mu 12} = \frac{1}{1 - p \left( 1 - \frac{C_m \varphi G_{m12}}{C_f \varphi G_{f12}} \right)}$$

$$\varphi_{\mu 12} \beta_v \rightarrow PL(47, J)$$

Strain magnification factor  $\varphi_{\mu 23}$  -

$$p = \begin{cases} \bar{k}_f^{1/\beta''_\epsilon} & \text{if } \beta''_\epsilon \neq 0 \\ \left(\frac{4\bar{k}_f}{\pi}\right)^{1/2} \gamma''_\epsilon & \text{if } \beta''_\epsilon = 0 \end{cases}$$

$$\varphi_{\mu 23} = \frac{1}{2(1-p) + (2p-1) \frac{C_{m\varphi} G_{m23}}{C_{f\varphi} G_{f23}}}$$

$$\varphi_{\mu 23} \beta_v \rightarrow PL(48, J)$$

Inputs to subroutine GSMF are the ply applied stresses ( $\sigma_{l11}$ ,  $\sigma_{l22}$ ,  $\sigma_{l12}$ , and  $\sigma_{l23}$ ), the void and apparent fiber content, the ply index, and ply, fiber and matrix elastic constants. The stresses  $\sigma_{l11}$ ,  $\sigma_{l22}$ , and  $\sigma_{l12}$  are transferred from PL(67,J) to PL(69,J), respectively. (J denotes ply index in this case.) The stress  $\sigma_{l23}$  is assigned the value of unity. The void and fiber contents are transferred from PL(1,J) and PL(2,J). The ply elastic properties are transferred from PL(31,J), PL(32,J), PL(37,J), and PL(38,J). The fiber and matrix properties are read in globally. The coefficients  $\beta_\epsilon$  are in VCF as follows:

$$\beta_\epsilon \rightarrow VCF = \begin{bmatrix} \beta_m, \beta'_m, \beta''_m, \tilde{\beta}_m, \beta_\epsilon, \beta'_\epsilon, \beta''_\epsilon, \beta_t, 0.0, 0.0 \\ \gamma_m, \gamma'_m, \gamma''_m, \tilde{\gamma}_m, \gamma_\epsilon, \gamma'_\epsilon, \gamma''_\epsilon, 0.0, 0.0, 0.0 \end{bmatrix}$$

The outputs of subroutine GSMF are the magnification factors stored in PL(43-48,J) as previously described. It is important to note that the magnification factor  $\varphi_{\mu 22}$  depends on the applied stress level; therefore, GSMF is called from the stress analysis subroutine COMPSA.

#### Subroutine COMPSA(M)

In this subroutine the stress and strain state of each ply are computed given the edge membrane forces, the ply temperature and the changes in curvature. In addition, two-ply combined-stress strength criteria and the interply delamination criterion are generated. The equations programmed for the  $i^{\text{th}}$  strain and stress states are

$$\{\epsilon_{li}\} = [R_{li}][A_{cx}]^{-1} < \{\bar{N}_{cx}\} + \{N_{c\Delta Tx}\} + [C_{cx}]\{w_{cbx}\} > -z[R_{li}]\{w_{cbx}\}$$

$$\begin{aligned} \{\sigma_{li}\} = [E_{li}]^{-1} [R_{li}][A_{cx}]^{-1} & \left\langle \{\bar{N}_{cx}\} + \{N_{c\Delta Tx}\} + [C_{cx}]\{w_{cbx}\} \right\rangle \\ & - [E_{li}]^{-1} \left\langle \Delta T_{li}\{\alpha_{li}\} + z[R_{li}]\{w_{cbx}\} \right\rangle \end{aligned}$$

The reference plane strains  $\epsilon_{csx}$  and the changes curvatures are computed from

$$\begin{Bmatrix} \{\epsilon_{csx}\} \\ \{w_{cbx}\} \end{Bmatrix} = \begin{bmatrix} [A_{cx}] & | & [C_{cx}] \\ | & | & | \\ [C_{cx}] & | & [D_{cx}] \end{bmatrix}^{-1} \begin{Bmatrix} \{N_{cx}\} \\ \{M_{cx}\} \\ \{N_{c\Delta Tx}\} \\ \{M_{c\Delta Tx}\} \end{Bmatrix}$$

when one or both of the membrane force and the moments are given.

The strains are generated locally in EPSL and SIGL, respectively, and are stored in PL(64,I) to PL(69,I). The matrices  $[R_{li}]$  and  $[E_{li}]$  are generated locally from information transferred from PL(14,I) and PL(31,I) to PL(42,I). The distance  $z_{li}$  and the ply temperature  $\Delta T_{li}$  are transferred from PL(11,I) and PL(50,I), respectively. The remaining matrices are

$$A_{cx} \rightarrow ACX$$

$$C_{cx} \rightarrow CPC$$

$$N_{c\Delta Tx} \rightarrow NSDT$$

$$\bar{N}_{cx} \rightarrow NSB_m$$

$$\bar{M}_{cx} \rightarrow MSB_m$$

$$w_{cbx} \rightarrow WXX_m \quad (\text{local curvature from bending analysis})$$

where  $m$  denotes the load condition.

It is important to note that the stress analysis in the coded form also handles the case where both the reference plane membrane strains and the local curvatures are given. In this case the ply strains are given by

$$\{\epsilon_{cx_i}\} = \{\epsilon_{csx}\} - z \{w_{cbx}\}$$

where  $\{\epsilon_{cx_i}\}$  are the  $i^{\text{th}}$  ply strains along the structural axis,  $\{\epsilon_{csx}\}$  are the reference plane membrane strains,  $z$  is the distance from the reference plane to the centroid of the  $i^{\text{th}}$  ply, and  $\{w_{cbx}\}$  are the local curvatures. They are read in the array  $D_{vm}$  where  $m$  denotes the load condition.

The corresponding  $i^{\text{th}}$  ply stresses are given by

$$\{\sigma_i\} = [E_{li}]^{-1} \left\langle [R_{li}] \{\epsilon_{cx_i}\} - \Delta T_{li} \{\alpha_{li}\} \right\rangle$$

where  $\{\sigma_{li}\}$  are the  $i^{\text{th}}$  ply stresses along the material axes,  $[E_{li}]$  are the  $i^{\text{th}}$  ply elastic constants about the material axes,  $[R_{li}]$  is the transformation matrix of the  $i^{\text{th}}$  ply,  $\{\epsilon_{cx_i}\}$  are the  $i^{\text{th}}$  ply strains along the structural axes as given by a previous equation,  $\Delta T_{li}$  is the temperature of the  $i^{\text{th}}$  ply, and  $\{\alpha_{li}\}$  are the thermal coefficients of expansion of the  $i^{\text{th}}$  ply along the material axes.

The displacement force relations are printed out under the title

Displacement	Displacement force relations	Forces
$\begin{Bmatrix} \{U_{cx}\} \\ \{W_{cx}\} \end{Bmatrix}$	$\begin{Bmatrix} [A_{cx}] [C_{cx}] \\ [C_{cx}] [D_{cx}] \end{Bmatrix}^{-1}$	$\begin{Bmatrix} \{N_{cx}\} \\ \{M_{cx}\} \end{Bmatrix}$

Two similar sets are printed out. In the first set the displacement and force vectors are in symbolic form. In the second set the displacement and force vectors have their numerical values. See outputs of trial cases (appendix C).

The failure criterion may be determined by either of the following methods.

(1) Modified distortion energy

$$F = 1 - \left[ \left( \frac{\sigma_{l11\alpha}}{S_{l11\alpha}} \right)^2 + \left( \frac{\sigma_{l22\beta}}{S_{l22\beta}} \right)^2 - K_{l12\beta} \frac{\sigma_{l11\alpha}}{|S_{l11\alpha}|} \frac{\sigma_{l22}}{|S_{l22}|} + \left( \frac{\sigma_{l12S}}{S_{l12S}} \right)^2 \right]_i \rightarrow PL(62, I)$$

The parameters  $\alpha$  and  $\beta$  are specified as follows:

$$\alpha = \begin{cases} T & \sigma_{l11} \geq 0 \\ C & \sigma_{l11} < 0 \end{cases}$$

$$\beta = \begin{cases} T & \sigma_{l22} \geq 0 \\ C & \sigma_{l22} < 0 \end{cases}$$

$$S_{l11\alpha} = \begin{cases} S_{l11T} & \alpha = T \\ \min(S_{l11C}, S_{l11CD}) & \alpha = C \end{cases}$$

$$S_{l22\alpha} = \begin{cases} S_{l22T} & \beta = T \\ S_{l22C} & \beta = C \end{cases}$$

$$K'_{l12\alpha\beta} = K'_{l12\alpha\beta} \frac{(1 + 4\nu_{l12} - \nu_{l13})E_{l22} + (1 - \nu_{l23})E_{l11}}{\left[ E_{l11}E_{l22}(2 + \nu_{l12} + \nu_{l13})(2 + \nu_{l21} + \nu_{l23}) \right]^{1/2}}$$

$$K'_{l12\alpha\beta} = \begin{cases} BET(1, 7) & \alpha, \beta = T \\ BET(2, 7) & \alpha = C, \beta = T \\ BET(1, 8) & \alpha = T, \beta = C \\ BET(2, 8) & \alpha, \beta = C \end{cases}$$

The multiplier of  $K'_{l12\alpha\beta}$  was generated in subroutine GLLSC and is stored in PL(61,I).

The constants  $K'_{l12\alpha\beta}$  constitute theory-experiment correlation factors.

(2) Hoffman's criterion (ref. 9):

$$S_{l11C} \leftarrow \min(S_{l11C}, S_{l11CD})$$

$$F = 1 - \left[ \frac{\sigma_{l11}^2 - \sigma_{l11}\sigma_{l22}}{S_{l11C}S_{l11T}} + \frac{\sigma_{l22}^2}{S_{l22C}S_{l22T}} + \frac{S_{l11C} - S_{l11T}}{S_{l11C}S_{l11T}} \sigma_{l11} \right. \\ \left. + \frac{S_{l22C} - S_{l22T}}{S_{l22C}S_{l22T}} \sigma_{l22} + \frac{\sigma_{l12}^2}{S_{l12S}^2} \right]_i \rightarrow PL(71, I)$$

$F > 0$  no failure

$F = 0$  incipient failure

$F < 0$  failure

The interply delamination criterion for the  $j^{th}$  interply layer at the  $m^{th}$  load condition is governed by

$$\left[ 1 - \left( \frac{|\Delta\varphi|}{\Delta\varphi_{del}} \right)_j \right] \rightarrow PL(63, I) \quad \text{when } i > 1$$

$$\Delta\varphi_j = \frac{1}{2} (\epsilon_{cyy} - \epsilon_{cxx})(\sin 2\theta_i - \sin 2\theta_{i-1}) + \frac{1}{2} \epsilon_{cxy}(\cos 2\theta_i - \cos 2\theta_{i-1})$$

$$\{\epsilon_{cx}\} = [A_{cx}]^{-1} \left\langle \{N_{cx}\} + \{N_c \Delta T_x\} + [C_{cx}] \{w_{cbx}\} \right\rangle$$

or as given by the displacement force equation described previously.

The inputs to the subroutine are the ply angle measured from the structural axes ( $\theta_i$  from  $PL(14, I)$ ), the distance from the reference plane to centroid of the ply ( $z_{li}$  from  $PL(11, I)$ ), the ply temperature ( $\Delta T_{li}$  from  $PL(50, I)$ ), the interply delamination limit ( $\Delta\varphi_{delj}$  from  $PL(60, I)$ ), and the ply thermoelastic properties stored in  $PL(24$  to  $26, -I)$  and  $PL(31$  to  $42, I)$ . The ply extensional and coupling rigidities  $A_{cx} = ACX$  and  $C_{cx} = CPC$ ; the local curvatures  $w_{cbx} = WXX$ ; the adjustment constants  $K'_{l12TT} = BET(1, 7)$ ,  $K'_{l12CT} = BET(2, 7)$ ,  $K'_{l12TC} = BET(1, 8)$ , and  $K'_{l12CC} = BET(2, 8)$ ; and the load conditions  $\bar{N}_{cx} = NBS(m)$ .

The subroutine outputs are the modified distortion energy  $PL(62, I)$ , Hoffman's cri-

criterion PL(71,I), the interply delamination criterion PL(63,I), and the adjacent ply relative rotation ( $\Delta\varphi_j$  from PL(70,I)).

#### IMMEDIATE EXTENSIONS

The code can be modified and supplemented to handle nonlinear material response, temperature dependent properties, and load envelopes for various angle ply composites. The details of these modifications will become apparent once the user has some experience in using this code.

Lewis Research Center,  
National Aeronautics and Space Administration,  
Cleveland, Ohio, October 7, 1970,  
129-03.

## APPENDIX A

### LIST OF CODE IDENTIFIERS

Engineering symbol	FORTRAN symbol code	Comment
$A_{cx}$	ACX	composite axial stiffness; generated in subroutine GPCFD2
$A_{cx}^R$	RAC	reduced axial stiffness; computed in subroutine GPCFD2
BIDE	Boolean	TRUE if interply effects are included; input
$C_{cx}$	CPC	composite coupling stiffness; generated in subroutine GPCFD2
$C_{e1}$	RESF	string with force variables in BLOCK DATA
$C_{e2}$	DISP	string with displacement variables in BLOCK DATA
CSANB	Boolean	TRUE if membrane and bending symmetry exists; input
$C_s$	String	composite title; MAIN PROGRAM format 4
$D_{cx}$	FLC	composite flexural rigidities; generated in subroutine GPCFD2
$D_{cx}^R$	RDC	reduced bending rigidities; computed in subroutine GPCFD2
$D_v$	DISV, DISVI	displacement vectors; DISVI is either read in MAIN PROGRAM, or is generated in subroutine COMPSA
$d_f$	DIAF	filament equivalent diameter; input
$E_f, E_{cf}$	ECF	filament elastic constants; generated in subroutine GECL
$E_l, E_{cl}$	ECL	ply elastic constants; generated in subroutine GECL
$E_m, E_{cm}$	ECM	matrix elastic constants; generated in subroutine GECL

Engineering symbol	FORTRAN symbol code	Comment
$E_{f11}, \ell_{11}, m_{11}$	EF11, EL11, EM11	filament, ply, and matrix normal moduli; filament and matrix moduli input
$G_{f12}, \ell_{12}, m_{11}$	EF12, EL12, EM12	filament, ply, and matrix shear moduli; filament and matrix shear moduli input
$H_j$	PL(9, I)	interply distortion energy coefficient; generated in MAIN PROGRAM
$H_{kc}$	CHK	array of constituents heat conductivities; input
$h_c$	HHC	composite heat capacity stored in PC(18) and PC(54)
$i, j$	I, J	index, generally ply or interply
$K_{c11}, c_{22}, c_{33}$	HK11, 22, 33	composite three-dimensional heat conductivities along the material axes in PC(15 to 17)
$K_{cxy}, c_{yy}, c_{xy}$	HK11, 22, 33	composite two-dimensional heat conductivities in PC(51 to 53)
$K_{f11}, \ell_{11}, m_{11}$	CHK	see $H_{kc}$
$K_f, v$	KF, V	apparent fiber and void volume ratios; input
$\bar{k}_f, m$	KFB, MB	actual fiber and matrix volume ratios
$k_{fl}, vl$	KFL, VL	ply apparent fiber and void volume ratios; input
$L_{sc}$	LSC	array of limiting conditions; input
$M_{c \Delta T_x}$	MSDT	thermal moments; generated in GPCFD2
$M_{cx}$	MSB	applied moment; input
$m$	M	load condition index
$\bar{N}_{cx}$	NBS	applied membrane loads; input
$N_{c \Delta T_x}$	NSDT	thermal force; generated in GPCFD2

Engineering symbol	FORTRAN symbol code	Comment
$N_f$	NFPE	number of filaments per end; input
$N_l$	NL	number of plies; input
$N_{lc}$	NLC	number of load conditions; input
$N_{pc}$	NPC	string PROPC length; input
$N_{pl}$	NPL	string PROP length; input
$P_c$	PC	composite properties array; generated in GACD3 and GPCFD2
$P_l$	PL	ply properties array; portions generated in all parts of the program
$P_{cp}$	PROPC	string PROPC; composite properties identifiers in GDCFD2
$P_{lp}$	PROP	string PROP; ply properties identifiers in MAIN PROGRAM
$Q_{f,i,p,r,s}$	QF,I,P,R,S	indices to print out string PROP
R	R	transformation matrix; GACD3, GPCFD2, COMPSA
RINDV	Boolean	T(TRUE) if displacements are read in; input
$S_{\gamma 11T}$ etc.	PL(51 to 59,I)	ply limit stresses; generated in GLLSC
$t_l$	TL	ply thickness; input if TLINP = TRUE, generated in GECL if TLINP = FALSE
TLINP	Boolean	F(FALSE) if ply thickness calculated internally; input
$w_{cb}$	$w_{xx}$	composite local curvatures relative to the structural axes
$\alpha_c$	CTE	composite coefficient of thermal expansion; three-dimensional in PC(12 to 14), two-dimensional in PC(48 to 50)

Engineering symbol	FORTRAN symbol code	Comment
$\alpha_{f, l, m}$	VAF, AL, AM	filament, ply, and matrix thermal coefficients of expansion; input and VAL generated in GECL
$\beta_e, \gamma_e$	VCF	correlation factors for ply thermoelastic properties and strain magnification factors; input
$\beta_h$	BTA	correlation factors for ply heat conductivities; input
$\beta_s$	BET	correlation factors for ply strength; input
$\delta_l$	PL(8, I)	interply layer thickness; generated in MAIN PROGRAM
$\epsilon_{csx}$	UX	reference plane membrane strains; solved in terms of $\bar{N}_{cx}$ or input
$\epsilon_l$	EPS, PL(64 to 66, I)	ply strains; generated in COMPSA
$\theta_{cs}$	THCS	angle between composite material and structural axes; input
$\theta_{li}, \theta_{lc}$	THLC	angle between ply material and composite axes; input
$\nu_{f12, l12, m12}$	NUF12, L12, M12	filament, ply, and matrix Poisson's ratio; input
$\pi$	PIE	constant; input
$\rho_{f, m, l}$	RHOF, M, L	filament and matrix weight density; input and generated in GECL
$\sigma_l$	SIGL, PL(67 to 69, I)	ply stresses; generated in COMPSA

## APPENDIX B

### COMPILED LISTING

```
C MULTILAYERED FILAMENTARY COMPOSITE ANALYSIS IS
C A COMPUTER CODE FOR THE LINEAR ANALYSIS OF MULTILAYERED FIBER
C COMPOSITES. THE ANALYSIS UTILIZES MICROMECHANICS, MACROMECHANICS,
C AND LAMINATE THEORY. THE ANALYSIS IS RESTRICTED TO MEMBRANE, PLATE
C AND THIN WALLED SHELL TYPE STRUCTURES. THE INPUTS ARE CONSTITUENT
C MATERIAL PROPERTIES, CORRELATION COEFFICIENTS AND COMPOSITE GEOMET-
C RY. THE LOAD CONDITIONS ARE EITHER FORCES OR DISPLACEMENTS AND
C TEMPERATURE AT THE DESIRED SECTION. THE OUTPUTS ARE STRESS/STRAIN
C /TEMPERATURE RELATIONS AND THEIR INVERSE, OTHER THERMAL
C PROPERTIES, STRENGTH PROPERTIES, STRESS ANALYSIS RESULTS AND
C THE MARGIN OF SAFETY.
C MFCA - MAIN PROGRAM
LOGICAL TLINP,C SANB,BIDE,RINDV
INTEGER QI,QS,QP,QR,QF
REAL NLF12,NUF23,NUF13,NUF21,NUF32,NUF31,
2 NUL12,NUL23,NUL13,NUL21,NUL32,NUL31,
2 NUM12,NUM23,NUM13,NUM21,NUM32,NUM31,
2 LSC,MLR,NBS,MBS,KVL,KFL,NSDT,MSDT,KVLJ,KFLJ
COMMON/MAGE/J
COMMON
2 EM22,EM11,EM23,EM12,NUM21,NUM12,NUM23,
2 EF22,EF11,EF23,EF12,NUF21,NUF12,NUF23,
2 EM33,NUM13,RHOM,ECM(3,3),EM13,VAM(3),AXC(3,3),FLC(3,3),
2 EF33,NUF13,RHOF,ECF(3,3),EF13,VAF(3),
2 BET(2,8),NBS(3,10),PL(71,50),WXX(3),LSC(6),PC(54),CPC(3,3),
2 CHK(3,4),BTA(4),TLINP,DIAF,NFPE,PIE,
2 MBS(3,10),RAC(3,3),DISV1(10,6),
2 CSANB,NPL,NL,NSDT(3),VCF(2,10),NUM32,BIDE,MSDT(3),RINDV
DIMENSION KVL(50),KFL(50),THLC(50),TL(50),MLR(3,10),PROP(71)
4 FORMAT(55H ) )
3 CONTINUE
READ(5,4)
WRITE(6,15)
WRITE(6,4)
WRITE(6,30)
5 FORMAT(5I5)
READ(5,5) NL,NPL,NPC,NFPE,NLC
10 FORMAT(5I5)
11 FORMAT(20H NL,NPL,NPC,NFPE,NLC)
WRITE(6,11)
WRITE(6,10) NL,NPL,NPC,NFPE,NLC
READ(5,35) EF11,EF22,EF33,NUF12,NUF23,NUF13,EF12,EF23,EF13,
2 EM11,EM22,EM33,NUM12,NUM23,NUM13,EM12,EM23,EM13
WRITE(6,70)
WRITE(6,37) EF11,EF22,EF33,NUF12,NUF23,NUF13,EF12,EF23,EF13,
2 EM11,EM22,EM33,NUM12,NUM23,NUM13,EM12,EM23,EM13
DATA(PROP(I), I = 1,71)/6HKV ,6HKF ,6HKFB ,6HKM ,
2 6HKMB ,6HRHOL ,6HTL ,6HDELT A ,6HILDC ,6HZB ,6HZGC ,6HTHCS ,
2 6HTHLC ,6HTHLS ,6HSC11 ,6HSC12 ,6HSC13 ,6HSC22 ,
2 6HSC23 ,6HSC33 ,6HSC44 ,6HSC55 ,6HSC66 ,6HCTE11 ,
2 6HCTE22 ,6HCTE33 ,6HHK11 ,6HHK22 ,6HHK33 ,6HHCL ,
2 6HEL11 ,6HEL22 ,6HEL33 ,6HGL23 ,6HGL13 ,6HGL12 ,
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2 6HNUL12 ,6HNUL21 ,6HNUL13 ,6HNUL31 ,6HNUL23 ,6HNUL32 ,
2 6HSMFK22,6HSMFD22,6HSMFS22,6HSMFC22,6HSMFS12,6HSMFS23,
2 6HILMFC ,6HTEMPD ,6HLSC11T,6HLSC11C,6HLSC11D,6HLSC22T,
2 6HLSC22C,6HLSC12 ,6HLSC23 ,6HLSCC23,6HLSCC13,6HLSCDF ,
2 6HKL12AB,6HMDEIE ,6HRELROT,6HEPS11 ,6HEPS22 ,6HEPS12 ,6HSIG11 ,
2 6HSIG22 ,6HSIG12 ,6HDELF1 ,6HHF C   /
15 FORMAT(1H1)
20 FORMAT(//47H LAYER PROPERTIES, ROWS-PROPERTY, COLUMNS-LAYER)
25 FORMAT(I3,3X,A6,2X,8E14.4)
30 FORMAT(//)
35 FORMAT(5E15.8)
37 FORMAT(10E13.5)
41 FORMAT(4H VCF)
  WRITE(6,41)
    READ(5,35) ((VCF(I,J),J = 1,10),I = 1,2)
  WRITE(6,37) ((VCF(I,J),J = 1,10),I = 1,2)
40 FORMAT(4H VAF)
  WRITE(6,40)
    READ(5,35) (VAF(I),I = 1,3)
  WRITE(6,37) (VAF(I),I = 1,3)
45 FORMAT(4H VAM)
  WRITE(6,45)
    READ(5,35) (VAM(I),I = 1,3)
  WRITE(6,37) (VAM(I),I = 1,3)
50 FORMAT(59H THERMAL CONDUCTIVITIES AND HEAT CAPACITIES OF CONSTITUE
2NTS)
55 FORMAT(4H CHK)
  WRITE(6,55)
    READ(5,35) ((CHK(I,J),J = 1,4),I = 1,3)
  WRITE(6,37) ((CHK(I,J),J = 1,4),I = 1,3)
60 FORMAT(4H BTA)
  WRITE(6,60)
    READ(5,35) (BTA(I),I = 1,4)
  WRITE(6,37) (BTA(I),I = 1,4)
65 FORMAT(4H PIE)
  WRITE(6,65)
    READ(5,35) PIE
  WRITE(6,37) PIE
70 FORMAT(/96H EF11,EF22,EF33,NUF12,NUF23,NUF13,EF12,EF23,EF13,EM11,E
2M22,EM33,NUM12,NUM23 NUM13,EM12,EM23,EM13)
80 FORMAT(/6H TLINP)
  WRITE(6,80)
75 FORMAT(L6)
  READ(5,75) TLINP
  WRITE(6,75) TLINP
85 FORMAT(/6H CSANB)
  WRITE(6,85)
    READ(5,75) CSANB
  WRITE(6,75) CSANB
87 FORMAT(/5H BIDE)
  WRITE(6,87)
    READ(5,75) BIDE
  WRITE(6,75) BIDE
88 FORMAT(/6H RINDV)
  WRITE(6,88)
    READ(5,75) RINDV
  WRITE(6,75) RINDV
90 FORMAT(/20H THCS,RHOF,RHOM,DIAF)
  WRITE(6,90)

```

```

      READ(5,35) THCS,RHOF,RHOM,DIAF
      WRITE(6,37) THCS,RHOF,RHOM,DIAF
95   FORMAT(4H KVL)
      WRITE(6, 95)
      READ(5,35) (KVL(I),I = 1,NL)
      WRITE(6,37) (KVL(I),I = 1,NL)
100  FORMAT(4H KFL)
      WRITE(6,100)
      READ(5,35) (KFL(I),I = 1,NL)
      WRITE(6,37) (KFL(I),I = 1,NL )
105  FORMAT(5H THLC)
      WRITE(6,105)
      READ(5,35) (THLC(I),I = 1,NL)
      WRITE(6,37) (THLC(I),I = 1,NL)
110  FORMAT(3H TL)
      WRITE(6,110)
      READ(5,35) (TL(I),I = 1,NL)
      WRITE(6,37) (TL(I),I = 1,NL)
111  FORMAT(6H PTEMP)
      WRITE(6,111)
      READ(5,35) (PL(50,I), I=1,NL)
      WRITE(6,37) (PL(50,I), I=1,NL)
115  FORMAT(/4H BET)
      WRITE(6,115)
      READ(5,35) ((BET(I,J),J = 1,8),I = 1,2)
      WRITE(6,37) ((BET(I,J),J = 1,8),I = 1,2)
120  FORMAT(/4H LSC)
      WRITE(6,120)
      READ(5,35) (LSC(I),I = 1,6)
      WRITE(6,37) (LSC(I),I = 1,6)
130  FORMAT(/4H NBS)
      WRITE(6,130).
      READ(5,35) ((NBS(I,J),J = 1,NLC),I = 1,3)
      WRITE(6,37) ((NBS(I,J),J = 1,NLC),I = 1,3)
131  FORMAT(/4H MBS)
      WRITE(6,131)
      READ(5,35) ((MBS(I,J),J = 1,NLC),I = 1,3)
      WRITE(6,37) ((MBS(I,J),J = 1,NLC),I = 1,3)
132  FORMAT(/6H DISV1)
      WRITE(6,132)
      READ(5,35) ((DISV1(I,J), J=1,6), I= 1,NLC)
      WRITE(6,37) ((DISV1(I,J), J= 1,6), I= 1,NLC)
140  CONTINUE
142  DO 145 J = 1,NL
      PL(1,J) = KVL(J)
      PL(2,J) = KFL(J)
      PL(7,J) = TL(J)
      PL(12,J) = THCS
      PL(13,J) = THLC(J)
      PL(14,J) = THCS+THLC(J)
      PL(13,J) = PL(13,J)*PIE/180.0
      PL(14,J) = PL(14,J)*PIE/180.0
      KVLJ = KVL(J)
      KFLJ = KFL(J)
145  CALL GECL(KVLJ,KFLJ)
      DO 155 J = 2,NL
      PL(9,J) = 0.0
      INE = J-1
      IF (.NOT. BIDE) GO TO 155

```

```

PL(9,J) = PL(8,J)+PL(8,INE)
PL(9,J) = PL(9,J)*PL(9,J)
PL(9,J) = (2.0*PL(8,J)*PL(8,INE))/PL(9,J)
PL(9,J) = 0.0186 *(1.0-PL(9,J))*EM12
155 PL(49,J) = 0.0093/(PL(8,J) + PL(8,INE))
C      READ IN DESIRED PLY PROPERTIES HERE. SEE FORMAT 111 AND THE
C      FOLLOWING THREE CARDS FOR SAMPLE INPUT.
CALL GACD3(3.0)
CALL GPCFD2
DO 195 M = 1,NLC
CALL CCMSA(M)
161 FORMAT(//33H FOR THIS CASE NBS(X,Y,XY-M) IS , 3F10.0)
162 FORMAT(//33H FOR THIS CASE MBS(X,Y,XY-M) IS , 3F10.0)
163 FORMAT(//79H FOR THIS CASE THE DISPLACEMENTS DISV(ECSXX,ECSYY,ECSX
2Y,WCBXX,WCBYY,WCBXY) ARE ,/1H , 6E15.5)
      WRITE(6,15)
      IF (RINDV) GO TO 165
      WRITE(6,161) (NBS(I,M), I = 1,3)
      WRITE(6,162) (MBS(I,M), I = 1,3)
      GO TO 166
165 CONTINUE
      WRITE(6,163) (DISV1(M,J), J = 1,6)
166 CONTINUE
      WRITE(6,20)
      WRITE(6,30)
      QF = 0
      QI = 0
      QR = 0
      QP = 0
      QP = NL/8
      QR = MOD(NL,8)
      IF (QP .LT. 1) GO TO 185
      DO 175 QS = 1,QP
         QI = (QS-1)*8+1
         QF = QS*8
         DO 176 I = 1,NPL
170      WRITE(6,25) I,PROP(I),(PL(I,J),J = QI,QF)
175      WRITE(6,15)
         IF(QR .LE. 0) GO TO 185
         QI = NL-QR+1
         QF = NL
         DO 186 I = 1,NPL
180      WRITE(6,25) I,PROP(I),(PL(I,J),J = QI,QF)
185      IF ((QP .NE. 0) .OR. (QR .LE. 0)) GO TO 195
         QI = 1
         QF = QR
         DO 196 I = 1,NPL
190      WRITE(6,25) I,PROP(I),(PL(I,J),J = QI,QF)
195      CONTINUE
      WRITE(6,15)
      GO TO 2
      END

```

```

C      SUBROUTINE INVA(N,A,C)
C      CALCULATES INVA IN C

      DIMENSION A(N,N),C(N,N),B(6,6),D(6,6)
      LOGICAL TLINP,CSANB,BIDE,RINDV
      REAL NLF12,NUF23,NUF13,NUF21,NUF32,NUF31,
2      NLL12,NUL23,NUL13,NUL21,NUL32,NUL31,
2      NLM12,NUM23,NUM13,NUM21,NUM32,NUM31,
2      LSC,MLR,NBS,MBS,KVL,KFL,NSDT,MSDT
      COMMON
2      EM22,EM11,EM23,EM12,NUM21,NUM12,NUM23,
2      EF22,EF11,EF23,EF12,NUF21,NUF12,NUF23,
2      EM33,NUM13,RHOM,ECM(3,3),EM13,VAM(3),AXC(3,3),FLC(3,3),
2      EF33,NUF13,RHOF,ECF(3,3),EF13,VAF(3),
2      BET(2,8),NBS(3,10),PL(7L,50),WXX(3),LSC(6),PC(54),CPC(3,3),
2      CHK(3,4),BTA(4),TLINP,DIAF,NFPE,PIE,
2      MBS(3,10),RAC(3,3),DISV1(10,6),
2      CSANB,NPL,NL,NSDT(3),VCF(2,10),NUM32,BIDE,MSDT(3),RINDV
      DO 365 I = 1,N
      DO 365 J = 1,N
      B(I,J) = A(I,J)
      C(I,J) = 0.0
      IF (I .NE .J) GO TO 365
      C(I,J) = 1.0
365 CONTINUE
      N1 = N-1
      DO 395 I = 1,N1
      DO 380 K = I,N
      IF ( B(K,I) .EQ. 0.0) GO TO 380
      S1 = B(K,I)
      DO 370 J = I,N
370  B(K,J) = B(K,J)/S1
      DO 375 J = 1,N
375  C(K,J) = C(K,J)/S1
380 CONTINUE
      IP1 = I+1
      DO 395 K = IP1,N
      IF (B(K,I) .EQ. 0.0) GO TO 395
      DO 385 J = 1,N
385  B(K,J) = B(K,J)-B(I,J)
      DO 390 J = 1,N
390  C(K,J) = C(K,J)-C(I,J)
395 CONTINUE

C      I LOOP ***
      S1 = B(N,N)
      IF (S1 .EQ. 0.0) GO TO 405
      B(N,N) = B(N,N)/S1
      DO 400 J = 1,N
400  C(N,J) = C(N,J)/S1
405  IF (S1 .NE. 0.0) GO TO 415
410  FORMAT(16H SINGULAR MATRIX)
      WRITE(6,410)
      GO TO 430
415  DO 420 II=2,N
      I=N+2-II
      IM1 = I-1
      DO 420 KK=1,IM1

```

```
K=I-KK  
DO 421 J = 1,N  
421 C(K,J) = C(K,J)-C(I,J)*B( K,I)  
420 B(K,I) = 0.0
```

```
C      END UPPER TRIANGLE REDUCTION
```

```
DO 425 I = 1,N  
DO 425 J = 1,N  
D(I,J) = 0.0  
DO 425 K = 1,N  
425 D( I,J) = D(I,J)+A(I,K)*C(K,J)  
430 CONTINUE  
      RETURN  
END
```

```

C SUBROUTINE GLLSC(J)
C GENERATES LIMIT STRESS CONDITIONS FOR SINGLE LAYER
LOGICAL TLINP,CSANB,BIDE,RINDV
REAL NLF12,NUF23,NUF13,NUF21,NUF32,NUF31,
2      NUL12,NUL23,NUL13,NUL21,NUL32,NUL31,
2      NUM12,NUM23,NUM13,NUM21,NUM32,NUM31,
2      LSC,MLR,NBS,MBS,KVL,KFL,NSDT,MSDT
COMMON
2      EM22,EM11,EM23,EM12,NUM21,NUM12,NUM23,
2      EF22,EF11,EF23,EF12,NUF21,NUF12,NUF23,
2      EF33,NUF13,RHOF,ECF(3,3),EF13,VAF(3),
2      EM33,NUM13,RHOM,ECM(3,3),EM13,VAM(3),AXC(3,3),FLC(3,3),
2      BET(2,8),NBS(3,10),PL(71,50),WXX(3),LSC(6),PC(54),CPC(3,3),
2      CHK(3,4),BTA(4),TLINP,DIAF,NFPE,PIE,
2      MBS(3,10),RAC(3,3),DISV1(10,6),
2      CSANB,NPL,NL,NSDT(3),VCF(2,10),NUM32,BIDE,MSDT(3),RINDV
PL(51,J) = LSC(1)*(BET(1,1)*PL(3,J)+(BET(1,2)*PL(5,J)*EM11/EF11))
PL(52,J) = LSC(2)*(BET(2,2)*PL(5,J)+(BET(2,1)*PL(3,J)*EF11/EM11))
PL(54,J) = BET(1,3)*(LSC(3)/PL(45,J))*PL(32,J)
PL(55,J) = BET(2,3)*(LSC(4)/PL(45,J))*PL(32,J)
PL(56,J) = BET(1,4)*(LSC(5)/PL(47,J))*PL(36,J)
PL(53,J) = BET(2,4)*PL(56,J) + BET(2,5)
PL(57,J) = BET(1,5)*(LSC(5)/PL(48,J))*PL(34,J)

C FOYE'S LONGITUDINAL COMPRESSIVE STRENGTH METHOD
S1 = PL(2,J)*(-1.0 + EM12/EF12) + 1.0
S1 = EM12/S1
S3 = PL(1,J)/(1.0 - PL(2,J))
S2 = 1.0 + S3
S3 = 1.0 - 2.0*S3 + S3*S3
S4 = S1*S3/S2/3.0

C END FOYE'S METHOD
I = S2
PL( I,J) = AMIN1(PL( I,J),S4)
IF (J .LE. 1) GO TO 445
PL(60,J) = BET(1,6)*(LSC(6)/PL(49,J))
JM1 = J-1
S1 = PL(10,JM1)+(0.5*PL(7,JM1))
S2 = 0.25*(PL(8,J)-PL(8,JM1))+PC(31)
ZJ = S1+S2
IF (ZJ .GE. 0.0) GO TO 435
S4 = PC(31)
435 IF (ZJ .LT. 0.0) GO TO 440
S4 = PC(2)-PC(31)
440 S3 = (S4*S4)-(ZJ*ZJ)
445 S1 = (1.0+(4.0*PL(37,J))-PL(39,J))*PL(32,J)
S2 = (1.0-PL(41,J))*PL(31,J)
S3 = 2.0+PL(37,J)+PL(37,J)
S3 = S3*(2.0+PL(38,J)+PL(41,J))

S3 = S3*PL(31,J)*PL(32,J)
S3 = SQRT(S3)
S4 = (S1+S2)/S3
450 PL(61,J) = S4
RETURN
END

```

\$IBFTC GACD32 DEBUG,DECK

```
SUBROUTINE GACD3(C)
C GENERATES 3-D AXIAL AND THERMAL CONSTANTS
DIMENSION EL(6,6),R(6,6),RT(6,6),S(6,6),D1(6,6),D2(6,6),
2 EC(6,6),ECI(6,6),CTL(6),CTC(6),CTD(6)
LOGICAL TLINP,CSANB,BIDE,RINDV,BWEC1
REAL NUF12,NUF23,NUF13,NUF21,NUF32,NUF31,
2 NUL12,NUL23,NUL13,NUL21,NUL32,NUL31,
2 NUM12,NUM23,NUM13,NUM21,NUM32,NUM31,
2 LSC,MLR,NBS,MBS,KVL,KFL,NSDT,MSDT
COMMON
2 EM22,EM11,EM23,EM12,NUM21,NUM12,NUM23,
2 EF22,EF11,EF23,EF12,NUF21,NUF12,NUF23,
2 EM33,NUM13,RHOM,ECM(3,3),EM13,VAM(3),AXC(3,3),FLC(3,3),
2 EF33,NUF13,RHOF,ECF(3,3),EF13,VAF(3),
2 BET(2,8),NBS(3,10),PL(71,50),WXX(3),LSC(6),PC(54),CPC(3,3),
2 CHK(3,4),BTA(4),TLINP,DIAF,NFPE,PIE,
2 MBS(3,10),RAC(3,3),DISV1(10,6),
2 CSANB,NPL,NL,NSDT(3),VCF(2,10),NUM32,BIDE,MSDT(3),RINDV
454 FORMAT(//27X,69H 3-D COMPOSITE STRAIN STRESS TEMPERATURE RELATION
2S - STRUCTURAL AXES//)
456 FORMAT(//33X,56H 3-D COMPOSITE STRESS STRAIN RELATIONS - STRUCTURA
2L AXES//)
457 FORMAT(/11X,6E14.4,5X,1E14.4)
458 FORMAT(/21X,6E14.4)
459 FORMAT(1H1)
BWEC1 = .TRUE.
461 DO 455 I = 1,6
    CTL(I)=0.0
    CTC(I)=0.0
    CTD(I)=0.0
    DO 455 J = 1,6
455 EC(I,J) = 0.0
    SRC = 0.0
    ST = 0.0
    DO 462 I = 15,18
462 PC(I) = 0.0
    IF (.NOT. BWEC1) GO TO 464
    DO 463 I = 51,54
463 PC(I) = 0.0
464 CONTINUE
    DO 500 J = 1,NL
    ST = ST+PL(7,J)
    SRC = SRC+(PL(6,J)*PL(7,J))
    EL(1,1) = PL(15,J)
    EL(1,2) = PL(16,J)
    EL(1,3) = PL(17,J)
    EL(2,2) = PL(18,J)
    EL(2,3) = PL(19,J)
    EL(3,3) = PL(20,J)
    EL(4,4) = PL(21,J)
    EL(5,5) = PL(22,J)
    EL(6,6) = PL(23,J)
    CTL(1) = PL(24,J)
    CTL(2) = PL(25,J)
    CTL(3) = PL(26,J)
    TH = PL(13,J)
```

```

IF (BwEC1) TH = PL(14,J)
R(2,2) = COS(TH)*COS(TH)
R(1,1) = R(2,2)
R(2,1) = SIN(TH)*SIN(TH)
R(1,2) = R(2,1)
R(3,3) = 1.0
R(4,4) = COS(TH)
R(5,4) = -SIN(TH)
R(5,5) = COS(TH)
R(4,5) = SIN(TH)
R(1,6) = 0.5 *SIN(2.0*TH)
R(2,6) = -R(1,6)
R(6,2) = SIN(2.0*TH)
R(6,6) = COS(2.0*TH)
R(6,1) = -R(6,2)
IF (J .LE. 1) GO TO 465
TH1 = PL(13,J)
JM1 = J-1
TH2 = PL(13,JM1)
S1 = (SIN(2.0*TH1)-SIN(2.0*TH2))
S2 = (COS(2.0*TH1)-COS(2.0*TH2))
S(2,2) = S1*S1
S(1,1) = S1*S1
S(2,1) = -S1*S1
S(1,2) = -S1*S1
S(6,1) = -S1*S2
S(1,6) = -S1*S2
S(6,2) = S1*S2
S(2,6) = S1*S2
S(6,6) = S2*S2
DO 460 K = 1,6
DO 460 L = 1,6
460 S(K,L) = 0.25*S(K,L)
465 DO 470 K = 1,6
    DO 470 L = K,6
470 EL(L,K) = EL(K,L)
    DO 475 K = 1,6
    DO 475 L = 1,6
475 RT(K,L) = R(L,K)
    DO 480 K = 1,6
    DO 480 L = 1,6
        D1(K,L) = 0.0
        DO 480 M = 1,6
480 D1(K,L) = D1(K,L)+(RT(K,M)*EL(M,L))
        DO 485 K = 1,6
        DO 485 L = 1,6
            D2(K,L) = 0.0
            DO 485 M = 1,6
485 D2(K,L) = D2(K,L)+(D1(K,M)*R(M,L))
            S1 = PL(7,J)
            S2 = PL(9,J)
            DO 490 K = 1,6
            DO 490 L = 1,6
490 EC(K,L) = EC(K,L) +(S1*D2(K,L))+(S2*S(K,L))
            PC(15) = PC(15) + PL(7,J)*(PL(27,J)*R(1,1)+ PL(28,J)*R(2,1))
            PC(16) = PC(16) + PL(7,J)*(PL(27,J)*R(2,1)+ PL(28,J)*R(1,1))
            PC(17) = PC(17) + PL(7,J)/PL(29,J)
            PC(18) = PC(18) + PL(7,J)*PL(30,J)

```

```

PC(53) = PC(53) + PL(7,J)*(PL(28,J) - PL(27,J))*R(6,2)/2.0
DO 500 K = 1,6
S3 = 0.0
DO 495 L = 1,6
495 S3 = S3+(S1*D1(K,L)*CTL(L))
500 CTD(K) = CTD(K)+S3
C      END J LOOP
DO 501 K = 1,6
DO 501 L = 1,6
501 EC(K,L) = (1.0/ST)*EC(K,L)
SRC = SRC/ST
CALL INVA(6,EC,ECI)
DO 510 K = 1,6
S3 = 0.0
DO 505 L = 1,6
505 S3 = S3+(ECI(K,L)*CTD(L))
510 CTC(K) = CTC(K)+(1.0/ST)*S3
IF (.NOT. BWEC1) GO TO 506
PC(48) = CTC(1)
PC(49) = CTC(2)
PC(50) = CTC(6)
PC(51) = PC(15)/ST
PC(52) = PC(16)/ST
PC(53) = PC(53)/ST
PC(54) = PC(18)/ST
506 CONTINUE
IF (.NOT. BWEC1) GO TO 511
WRITE(6,459)
WRITE(6,454)
WRITE(6,457) ((ECI(I,J),J = 1,6),CTC(I),I = 1,6)
WRITE(6,456)
WRITE(6,458) ((EC(I,J),J = 1,6),I = 1,6)
WRITE(6,459)
BWEC1 = .FALSE.
GO TO 461
C      TRANSFER COMPOSITE PROPERTIES IN PC
511 PC(1) = SRC
PC(2) = ST
PC(3) = EC(1,1)
PC(4) = EC(1,2)
PC(5) = EC(1,3)
PC(6) = EC(2,2)
PC(7) = EC(2,3)
PC(8) = EC(3,3)
PC(9) = EC(4,4)
PC(10) = EC(5,5)
PC(11) = EC(6,6)
PC(12) = CTC(1)
PC(13) = CTC(2)
PC(14) = CTC(3)
DO 515 M = 15,18
515 PC(M) = PC(M)/ST
PC(17) = 1.0/PC(17)
PC(19) = 1.0/ECI(1,1)
PC(20) = 1.0/ECI(2,2)
PC(21) = 1.0/ECI(3,3)
PC(22) = 1.0/ECI(4,4)
PC(23) = 1.0/ECI(5,5)
PC(24) = 1.0/ECI(6,6)

```

```
PC(25) = -ECI(2,1)/ECI(1,1)
PC(26) = -ECI(1,2)/ECI(2,2)
PC(27) = -ECI(3,1)/ECI(1,1)
PC(28) = -ECI(1,3)/ECI(3,3)
PC(29) = -ECI(3,2)/ECI(2,2)
PC(30) = -ECI(2,3)/ECI(3,3)
RETURN
END
```

```
$IBFTC BLOCK1 DECK,LIST
```

```
BLOCK DATA
COMMON/GP.COM/RESF(6),DISP(6)
DATA(DISP(I),I = 1,6)/6HUX    ,6HVY    ,6HVXPUY ,6HWXX   ,
2 6HWYY  ,6HXY    /
DATA(RESF(I),I = 1,6)/6HNX    ,6HNY    ,6HNXY    ,6HMX   ,
2 6HMY  ,6HMX    /
END
```

```

SUBROUTINE GPCFD2
C GENERATES THE REQUIRED SECTION PROPERTIES FOR LINEAR BENDING
C THEORY OF MULTILAYERED FILAMENTARY COMPOSITE
REAL MT,NT
DIMENSION EL(3,3),R(3,3),RT(3,3),S(3,3),EC(3,3),CC(3,3),
2 FC(3,3),D1(3,3),D2(3,3),D3(3,3),D4(3),MT(3),NT(3),
2 CTL(3),PROPC(54),RDC(3,3)
LOGICAL TLINP,CSANB,BIDE,RINDV
REAL NUF12,NUF23,NUF13,NUF21,NUF32,NUF31,
2 NUL12,NUL23,NUL13,NUL21,NUL32,NUL31,
2 NUM12,NUM23,NUM13,NUM21,NUM32,NUM31,
2 LSC,MLR,NBS,MBS,KVL,KFL,NSDT,MSDT
COMMON
2 EM22,EM11,EM23,EM12,NUM21,NUM12,NUM23,
2 EF22,EF11,EF23,EF12,NUF21,NUF12,NUF23,
2 EM33,NUM13,RHOM,ECM(3,3),EM13,VAM(3),AXC(3,3),FLC(3,3),
2 EF33,NUF13,RHOF,ECF(3,3),EF13,VAF(3),
2 BET(2,8),NBS(3,10),PL(71,50),WXX(3),LSC(6),PC(54),CPC(3,3),
2 CHK(3,4),BTA(4),TLINP,DIAF,NFPE,PIE,
2 MBS(3,10),RAC(3,3),DISV1(10,6),
2 CSANB,NPL,NL,NSDT(3),VCF(2,10),NUM32,BIDE,MSDT(3),RINDV
COMMON/GPCOM/RESF(6),DISP(6)
DATA PROPC(I),I = 1,54)/6HRHOC ,6HTC ,6HCC11 ,6HCC12 ,
2 6HCC13 ,6HCC22 ,6HCC23 ,6HCC33 ,6HCC44 ,6HCC55 ,6HCC66 ,
2 6HCTE11 ,6HCTE22 ,6HCTE33 ,6HHK11 ,6HHK22 ,
2 6HHK33 ,6HHC ,6HEC11 ,6HEC22 ,6HEC33 ,
2 6HEC23 ,6HEC31 ,6HEC12 ,6HNUC12 ,6HNUC21 ,6HNUC13 ,
2 6HNUC31 ,6HNUC23 ,6HNUC32 ,6HZCGC ,6HB2DEC ,6HCC11 ,
2 6HCC12 ,6HCC13 ,6HCC22 ,6HCC23 ,6HCC33 ,6HEC11 ,6HEC22 ,
2 6HEC12 ,6HNUC12 ,6HNUC21 ,6HCSN13 ,6HCSN31 ,6HCSN23 ,
2 6HCSN32 ,6HCTE11 ,6HCTE22 ,6HCTE12 ,6HHK11 ,6HHK22 ,6HHK12 ,
2 6HHHC /
205 FORMAT(A6,4X,3E14.4,1X,3E14.4,A6,1E14.4)
210 FORMAT(/)
215 FORMAT(//)
216 FORMAT(1H1)
220 FORMAT(//7H FORCES,34X,29H FORCE DISPLACEMENT RELATIONS,
2 29X,6H DISPL,7X,15H THERMAL FORCES)
225 FORMAT(//77H COMPOSITE PROPERTIES - VALID ONLY FOR CONSTANT TEMPER
2ATURE THROUGH THICKNESS)
226 FORMAT(60H LINES 1 TO 31 3-D COMPOSITE PROPERTIES ABOUT MATERIAL
2AXES)
227 FORMAT(63H LINES 33 TO 54 2-D COMPOSITE PROPERTIES ABOUT STRUCTUR
2AL AXES)
C CZ = 0.0
DO 230 J = 1,NL
C CG IS TAKEN AT THE GEOMETRIC CENTER
CZ = CZ+PL(7,J)
230 PL(10,J) = CZ-(0.5*PL(7,J))
PC(31) = CZ/2.0
ZBC = PC(31)
DO 235 I = 1,NL
235 PL(11,I) = PL(10,I)-ZBC
C END CALCULATIONS FOR CG
DO 240 K = 1,3
MT(K) = 0.0
240 NT(K) = 0.0
DO 245 K = 1,3
DO 245 L = 1,3

```

```

EC(K,L) = 0.0
FC(K,L) = 0.0
CC(K,L) = 0.0
S(K,L) = 0.0
R(K,L) = 0.0
245 EL(K,L) = 0.0
C BEGIN J LOOP****
DO 290 J = 1,NL
EL(1,1) = 1.0/PL(31,J)
EL(2,2) = 1.0/PL(32,J)
EL(3,3) = 1.0/PL(36,J)
EL(1,2) = -PL(38,J)/PL(32,J)
EL(2,1) = -PL(37,J)/PL(31,J)
CALL INVA(3,EL,EL)
TH = PL(14,J)
R(1,1) = COS(TH)*COS(TH)
R(2,2) = COS(TH)*COS(TH)
R(1,2) = SIN(TH)*SIN(TH)
R(2,1) = SIN(TH)*SIN(TH)
R(1,3) = 0.5*SIN(2.0*TH)
R(3,2) = SIN(2.0 *TH)
R(3,3) = COS(2.0 *TH)
R(2,3) = -R(1,3)
R(3,1) = -R(3,2)
DO 250 K = 1,3
DO 250 L = 1,3
250 RT(K,L) = R(L,K)
IF(J .LE. 1) GO TO 255
S1 = SIN(2.0*TH)
JM1 = J-1
S2 = SIN(2.0*PL(13,JM1 ))
S3 = COS(2.0*TH)
S4 = COS(2.0*PL(13,JM1))
S(2,2) = (S1-S2)*(S1-S2)
S(1,1) = (S1-S2)*(S1-S2)
S(2,1) = -S(1,1)
S(1,2) = S(2,1)
S(3,3) = (S3-S4)*(S3-S4)
S(3,1) = -(S1-S2)*(S3-S4)
S(1,3) = -(S1-S2)*(S3-S4)
S(3,2) = (S1-S2)*(S3-S4)
S(2,3) = S(3,2)
255 S4 = 0.5*PL(7,J)
S1 = PL(10,J)-PC(31)+S4
S2 = PL(10,J)-PC(31)-S4
S5 = 0.5*(S1*S1-S2*S2)
IF (J .LE. 1) GO TO 265
DO 260 K = 1,3
DO 260 L = 1,3
260 S(K,L) = 0.25*PL(9,J)*S(K,L)
S6 = 0.25*(PL(8,J)-PL(8,JM1))
S6 = S6+S4+PL(10,JM1)-PC(31)
265 IF (J .GT. 1) GO TO 270
S5 = 0.0
270 DO 275 K = 1,3
DO 275 L = 1,3
D1(K,L) = 0.0
DO 275 M = 1,3

```

```

275 D1(K,L) = D1(K,L)+(RT(K,M)*EL(M,L))
DO 280 K = 1,3
DO 280 L = 1,3
D2(K,L) = 0.0
DO 280 M = 1,3
280 D2(K,L) = D2(K,L)+(D1(K,M)*R(M,L))
DO 285 K = 1,3
DO 285 L = 1,3
S7 = 0.0
S7 = (S1-S2)*D2(K,L)+S(K,L)
EC(K,L) = EC(K,L) + S7
S7 = 0.0
S7 = S5*D2(K,L) + S6*S(K,L)
CC(K,L) = CC(K,L)+S7
S7 = 0.0
S7 = (1.0/3.0)*((S1*S1*S1)-(S2*S2*S2))*D2(K,L)+((S6*S6)*S(K,L))
285 FC(K,L) = FC(K,L)+S7
CTL(1) = PL(24,J)
CTL(2) = PL(25,J)
CTL(3) = 0.0
DO 290 K = 1,3
D4(K) = 0.0
DO 291 L = 1,3
291 D4(K) = D4(K)+(D1(K,L)*CTL(L))
NT(K) = NT(K)+(PL(50,J)*D4(K)*PL(7,J))
290 MT(K) = MT(K)+(S5*PL(50,J)*D4(K))
C END J LOOP****
DO 295 K = 1,3
DO 295 L = 1,3
295 D1(K,L) = EC(K,L)/CZ
CALL INVA(3,D1,D2)
PC(33) = D1(1,1)
PC(34) = D1(1,2)
PC(35) = D1(1,3)
PC(36) = D1(2,2)
PC(37) = D1(2,3)
PC(38) = D1(3,3)
PC(39) = 1.0/D2(1,1)
PC(40) = 1.0/D2(2,2)
PC(41) = 1.0/D2(3,3)
PC(42) = -D2(2,1)/D2(1,1)
PC(43) = -D2(1,2)/D2(2,2)
PC(44) = -D2(3,1)/D2(1,1)
PC(45) = -D2(1,3)/D2(3,3)
PC(46) = -D2(3,2)/D2(2,2)
PC(47) = -D2(2,3)/D2(3,3)
DO 305 I = 1,3
DO 305 J = 1,3
AXC(I,J) = EC(I,J)
CPC(I,J) = CC(I,J)
300 FLC(I,J) = FC(I,J)
NSDT(I) = NT(I)
305 MSDT(I) = MT(I)
WRITE(6,225)
WRITE(6,226)
WRITE(6,227)
DO 310 I = 1,54
310 WRITE(6,320) I,PROPC(I),PC(I)

```

```

32C FORMAT(I3,3X,A6,E14.4)
  WRITE(6,216)
  WRITE(6,220)
  WRITE(6,210)
33C FORMAT(2X,A6,4X,3E14.4,1X,3E14.4,3X,A6,4X,E14.4)
  DO 335 I = 1,3
  WRITE(6,210)
335 WRITE(6,330) RESF(I),(EC(I,J),J = 1,3),(CC(I,J),J = 1,3),
  2 DISP(I),NT(I)
  WRITE(6,210)
  DO 340 I = 4,6
  IM3 = I-3
  WRITE(6,210)
340 WRITE(6,330) RESF(I),(CC(J,IM3),J = 1,3),(FC(IM3,J),J = 1,3),
  2 DISP(I),MT(IM3)
  CALL INVA(3,EC,EC)
  DO 345 I = 1,3
  DO 345 J = 1,3
  FC(I,J) = 0.0
  DO 345 K = 1,3
  DO 345 L = 1,3
345 FC(I,J) = FC(I,J)+CC(I,K)*EC(K,L)*CC(L,J)
  DO 350 I = 1,3
  DO 350 J = 1,3
350 RDC(I,J) = FLC(I,J) - FC(I,J)
  WRITE(6,215)
355 FORMAT(27H REDUCED BENDING RIGIDITIES)
  WRITE(6,355)
  WRITE(6,210)
360 FORMAT(9E13.5)
  WRITE(6,360) ((RDC(I,J), J = 1,3) , I = 1,3)
  WRITE(6,215)
  DO 361 I = 1,3
  DO 361 J = 1,3
361 FC(I,J) = FLC(I,J)
  CALL INVA(3,FC,FC)
  DO 362 I = 1,3
  DO 362 J = 1,3
  D3(I,J) = 0.0
  DO 362 K = 1,3
  DO 362 L = 1,3
362 D3(I,J) = D3(I,J) + CC(I,K)*FC(K,L)*CC(L,J)
  DO 363 I = 1,3
  DO 363 J = 1,3
363 RAC(I,J) = AXC(I,J) - D3(I,J)
  WRITE(6,215)
364 FORMAT(25H REDUCED STIFFNESS MATRIX)
  WRITE(6,364)
  WRITE(6,360) ((RAC(I,J),J = 1,3),I = 1,3)
  WRITE(6,215)
  RETURN
  END

```

```

SUBROUTINE GPHK(CF,CM,R,Q,CP)
REAL R
LOGICAL TLINP,C SANB,BIDE,RINDV
REAL NLF12,NUF23,NUF13,NUF21,NUF32,NUF31,
2     NUL12,NUL23,NUL13,NUL21,NUL32,NUL31,
2     NUM12,NUM23,NUM13,NUM21,NUM32,NUM31,
2     LSC,MLR,NBS,MBS,KVL,KFL,NSDT,MSDT
COMMON
2     EM22,EM11,EM23,EM12,NUM21,NUM12,NUM23,
2     EF22,EF11,EF23,EF12,NUF21,NUF12,NUF23,
2     EM33,NUM13,RHOM,ECM(3,3),EM13,VAM(3),AXC(3,3),FLC(3,3),
2     EF33,NUF13,RHOF,ECF(3,3),EF13,VAF(3),
2     BET(2,8),NBS(3,10),PL(71,50),WXX(3),LSC(6),PC(54),CPC(3,3),
2     CHK(3,4),BTA(4),TLINP,DIAF,NFPE,PIE,
2     MBS(3,10),RAC(3,3),DISV1(10,6),
2     C SANB,NPL,NL,NSDT(3),VCF(2,10),NUM32,BIDE,MSDT(3),RINDV
C GENERATES PLY HEAT CONDUCTIVITIES
S1 = (1.0-CM/CF)
S2 = Q*SQRT(R)
S1 = (1.0/S2)-S1
IF(S1 .GT.0.0) GO TO 525
520 FORMAT(23H BETA TOO LARGE IN GPHK)
WRITE(6,520)
525 IF (S1 .LE. 0.0) GO TO 530
CP = 1.0-S2+(1.0/S1)
530 CP = CP*CM
RETURN
END

```

```

SUBROUTINE GECL(KV,KF)
C GENERATES ECL FROM CONSTITUENT PROPERTIES
REAL KV,KF,KFB,KMB,EM1,EM2,INVECL,KM
DIMENSION CFL(3,3),VAL(3),CML(3,3),CMLT(3,3),EM1(3,3),EM2(3,3),
2 ECL(3,3),CFLT(3,3),INVECL(3,3)
LOGICAL TLINP,CANSB,BIDE,RINDIV
REAL NUF12,NUF23,NUF13,NUF21,NUF32,NUF31,
2 NUL12,NUL23,NUL13,NUL21,NUL32,NUL31,
2 NUM12,NUM23,NUM13,NUM21,NUM32,NUM31,
2 LSC,MER,NBS,RHS,KVL,KFL,NSDT,MSDT
COMMON/MAGE/J
COMMON/N
2 EM22,EM11,EM23,EF12,NUM21,NUM12,NUM23,
2 EF22,EF11,EF23,EF12,NUF21,NUF12,NUF23,
2 EM33,NUM13,RHOM,LCM(3,3),EM13,VAM(3),AXC(3,3),ECL(3,3),
2 EF33,NUF13,RHOF,ECH(3,3),EF13,VAF(3),
2 BET(2,8),NBS(3,10),PL(71,50),WXX(3),LSC(4),PG(54),CPC(3,4),
2 CHK(3,4),BTA(4),TLINP,DIAF,NRPE,PIE,
2 MBS(3,10),RAC(3,3),DISV1(10,6),
2 CSAVB,NPL,NL,NSDT(3),VCF(2,10),NUM32,BIDE,MSDT(3),TINDV
IF (EF11 .NE. EF22) GO TO 535
NUF21 = NUF12
EF12 = EF11/(2.0*(1.0+NUF12))
535 IF (EF11 .EQ. EF22) GO TO 540
NUF21 = NUF12*(EF22/EF11)
540 IF (EF11 .NE. EF33) GO TO 545
NUF31 = NUF13
EF13 = EF11/(2.0*(1.0+NUF13))
545 IF (EF11 .EQ. EF33) GO TO 550
NUF31 = NUF13*(EF33/EF11)
550 IF (EF22 .NE. EF33) GO TO 555
NUF32 = NUF23
EF23 = EF22/(2.0*(1.0+NUF23))
555 IF (EF22 .EQ. EF33) GO TO 560
NUF32 = NUF23*(EF33/EF22)
560 IF (EM11 .NE. EM22) GO TO 565
NUM21 = NUM12
EM12 = EM11/(2.0*(1.0+NUM12))
565 IF (EM11 .EQ. EM22) GO TO 570
NUM21 = NUM12*(EM22/EM11)
570 IF (EM11 .NE. EM33) GO TO 575
NUM31 = NUM13
EM13 = EM11/(2.0*(1.0+NUM13))
575 IF (EM11 .EQ. EM33) GO TO 580
NUM31 = NUM13*(EM33/EM11)
580 IF (EM22 .NE. EM33) GO TO 585
NUM32 = NUM23
EM23 = EM22/(2.0*(1.0+NUM23))
585 IF (EM22 .EQ. EM33) GO TO 590
NUM32 = NUM23*(EM33/EM22)
590 KFB = (1.0-KV)*KF
KMB = (1.0-KF)*(1.0-KV)
CF = KFB/KF
KM = 1.0-KF
PL(3,J) = KFB
PL(4,J) = 1.0-KF
PL(5,J) = KMB
PL(6,J) = RHOM*KMB+RHOF*KFB
IF (.NOT. TLINP) PL(7,J)=SQRT(PIE*(FLOAT(NRPE))/(4.0*KFB))*DIAF
IF (.NOT. TLINP) PL(7,J) = PL(7,J)/SQRT(VCF(1,8))
S1 = PIE/4.0/KFB

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```

S1 = SQRT(S1)-1.0
PL(8,J) = S1*DIAF
IF (VCF(1,1) .EQ. 0.0) GO TO 595
CM = (1.0/KMB)**(1.0/VCF(1,1))
595 IF (VCF(1,1) .NE. 0.0) GO TO 600
CM = VCF(2,1)
600 CM = (1.0-KV)*CM
A = ((1.0/EF11)+(1.0/EM11)*(KFB/KMB))
B = ((1.0/EM11)+(1.0/EF11)*(KMB/KFB))
ECF(1,1) = 1.0/EF11
ECM(1,1) = 1.0/EM11
ECF(1,2) = -NUF21/EF22
ECM(1,2) = -NUM21/EM22
ECF(1,3) = -NUF31/EF33
ECM(1,3) = -NUM31/EM33
ECF(2,2) = 1.0/EF22
ECM(2,2) = 1.0/EM22
ECF(2,1) = -NUF12/EF11
ECM(2,1) = -NUM12/EM11
ECF(2,3) = -NUF32/EF33
ECM(2,3) = -NUM32/EM33
ECF(3,3) = 1.0/EF33
ECM(3,3) = 1.0/EM33
ECF(3,1) = -NUF13/EF11
ECM(3,1) = -NUM13/EM11
ECF(3,2) = -NUF23/EF22
ECM(3,2) = -NUM23/EM22
DO 605 I = 1,3
DO 605 L = 1,3
CML(I,L) = 0.0
605 CFL(I,L) = 0.0
CFL(1,1) = 1.0/(A*KMB*EM11)
CFL(2,2) = 1.0/CF
CFL(3,3) = 1.0/CF
CFL(1,2) = (1.0/A)*((NUF21/(CF*EF22))-(NUM21/(CM*EM22)))
CFL(1,3) = (1.0/A)*((NUF31/(CF*EF33))-(NUM31/(CM*EM33)))
CML(1,1) = 1.0/(B*KFB*EF11)
CML(2,2) = 1.0/CM
CML(3,3) = 1.0/B
CML(1,2) = (1.0/B)*((NUM21/(CM*EM22))-(NUF21/(CF*EF22)))
CML(1,3) = (1.0/B)*((NUM31/(CM*EM33))-(NUF31/(CF*EF33)))
DO 610 I = 1,3
DO 610 L = 1,3
CFLT(I,L) = CFL(L,I)
610 CMLT(I,L) = CML(L,I)
DO 620 I = 1,3
DO 620 L = 1,3
IM2(I,L) = 0.0
IM1(I,L) = 0.0
DO 620 K = 1,3
IM1(I,L) = IM1(I,L)+(CFLT(I,K)*ECF(K,L))
620 IM2(I,L) = IM2(I,L)+(CMLT(I,K)*ECM(K,L))
DO 635 I = 1,3
DO 635 L = 1,3
S2 = 0.0
S1 = 0.0
DO 630 K = 1,3
S1 = S1+(IM1(I,K)*CFL(K,L))

```

```

635 S2 = S2+(IM2(I,K)*CML(K,L))
635 ECL(1,L) = S1*KFB+S2*KMB
EL11 = 1.0/ECL(1,1)
EL22 = 1.0/ECL(2,2)
EL33 = 1.0/ECL(3,3)
NUL12 = -ECL(2,1)/ECL(1,1)
NUL21 = -ECL(1,2)/ECL(2,2)
NUL13 = -ECL(3,1)/ECL(1,1)
NUL31 = -ECL(1,3)/ECL(3,3)
NUL23 = -ECL(3,2)/ECL(2,2)
NUL32 = -ECL(2,3)/ECL(3,3)
IF (VCF(1,2) .EQ. 0.0) GO TO 640
CM = (1.0/KM)**(1.0/VCF(1,2))
640 IF (VCF(1,2) .NE. 0.0) GO TO 645
CM = VCF(2,2)
645 CM = (1.0-KV)*CM
S1 = (EM12/(CF*CF*EF12))*KFB
S2 = KMB/(CM*CM)
EL12 = EM12/(S1+S2)
S1 = (EM13/(CF*CF*EF13))*KFB
S2 = KM3/(CM*CM)
EL13 = EM13/(S1+S2)
IF (VCF(1,3) .EQ. 0.0) GO TO 650
CM = (1.0/KM)**(1.0/VCF(1,3))
650 IF (VCF(1,3) .NE. 0.0) GO TO 655
CM = VCF(2,3)
655 CM = (1.0-KV)*CM
S1 = (EM23/(CF*CF*EF23))*KFB
S2 = KM3/(CM*CM)
EL23 = EM23/(S1+S2)
IF (VCF(1,4) .EQ. 0.0) GO TO 656
CM = (1.0/KM)**(1.0/VCF(1,4))
656 IF (VCF(1,4) .NE. 0.0) GO TO 657
CM = VCF(2,4)
657 CM = (1.0-KV)*CM
DO 658 I = 1,3
DO 658 L = 1,3
CFL(I,L) = 0.0
658 CML(I,L) = 0.0
CFL(1,1) = 1.0/(A*KMB*EM11)
CFL(2,2) = 1.0/CF
CFL(3,3) = 1.0/CF

```

```

CFL(1,2) = (1.0/A)*((NUF21/(CF*EF22))-(NUM21/(CM*EM22)))
CFL(1,3) = (1.0/A)*((NUF31/(CF*EF33))-(NUM31/(CM*EM33)))
CML(1,1) = 1.0/(B*KFB*EF11)
CML(2,2) = 1.0/CM
CML(3,3) = 1.0/CM
CML(1,2) = (1.0/B)*((NUM21/(CM*EM22))-(NUF21/(CF*EF22)))
CML(1,3) = (1.0/B)*((NUM31/(CM*EM33))-(NUF31/(CF*EF33)))
DO 660 I = 1,3
DO 660 L = 1,3
CFLT(I,L) = CFL(L,I)
660 CMLT(I,L) = CML(L,I)
DO 661 I = 1,3
VAL(I) = 0.0
S1 = 0.0
S2 = 0.0
DO 661 L = 1,3
S1 = S1+(CFLT(I,L)*VAF(L))
S2 = S2+(CMLT(I,L)*VAM(L))
661 VAL(I) = S1*KFB+S2*KMB
CALL INVA(3,ECL,INVECL)
PL(15,J) = INVECL(1,1)
PL(16,J) = INVECL(1,2)
PL(17,J) = INVECL(1,3)
PL(18,J) = INVECL(2,2)
PL(19,J) = INVECL(2,3)
PL(20,J) = INVECL(3,3)
PL(21,J) = EL23
PL(22,J) = EL13
PL(22,J) = EL23
PL(23,J) = EL12
PL(24,J) = VAL(1)
PL(25,J) = VAL(2)
PL(26,J) = VAL(2)
PL(31,J) = EL11
PL(32,J) = EL22
PL(33,J) = EL33
PL(34,J) = EL23
PL(35,J) = EL12
PL(36,J) = EL12
PL(37,J) = NUL12
PL(39,J) = NUL13
PL(38,J) = NUL21
PL(40,J) = NUL21
PL(41,J) = NUL23
PL(42,J) = NUL23
PL(30,J) = (CHK(1,4)*RHOF*KFB+CHK(2,4)*RHOM *KMB)/PL(6,J)
DO 665 L = 1,3
S1 = 2.0* BTA(1)*CHK(2,L)+CHK(3,4)
S2 = KV*(CHK(2,L)-CHK(3,4))
665 CHK(3,L) = CHK(2,L)*(S1-2.0*S2)/(-S2+S1/BTA(1))
PL(27,J) = BTA(2)*KFB*CHK(1,1)+(1.0-KF)*CHK(3,1)
DO 670 L = 2,3
L26 = 26+L
CHK1L = CHK(1,L)
CHK3L = CHK(3,L)
LP1 = L+1
BTAL = BTA(LP1)
CALL GPHK(CHK1L,CHK3L,KFB,BTAL,PLL26J)
670 PL(L26,J) = PLL26J
RETURN
END

```

```

C      SUBROUTINE GSMF(SL11,SL22,SL12,SL23,KV,KF,J)
C      GENERATES TRANSVERSE AND TWO SHEAR MAGNIFICATION FACTORS
      REAL KV,KF,KFB,KMB,MF22,MF12,MF23
      DIMENSION VMF(10)
      LOGICAL TLINP,C SANB,BIDE,RINDV
      REAL NUF12,NUF23,NUF13,NUF21,NUF32,NUF31,
      2      NUL12,NUL23,NUL13,NUL21,NUL32,NUL31,
      2      NUM12,NUM23,NUM13,NUM21,NUM32,NUM31,
      2      LSC,MLR,NBS,MBS,KVL,KFL,NSDT,MSDT
      COMMON
      2      EM22,EM11,EM23,EM12,NUM21,NUM12,NUM23,
      2      EF22,EF11,EF23,EF12,NUF21,NUF12,NUF23,
      2      EF33,NUF13,RHOF,EUF(3,3),EF13,VAF(3),
      2      EM32,NJM13,RHO4,ECM(3,3),EM13,VAM(3),AXC(3,3),FLC(3,3),
      2      BET(2,8),NBS(3,10),PL(71,50),WXX(3),LSC(6),PC(54),CPC(3,3),
      2      CHK(3,4),BTA(4),TLINP,DIAF,NFPE,PIE,
      2      MBS(3,10),RAC(3,3),DISV1(10,6),
      2      CSANB,NPL,NL,NSDT(3),VCF(2,10),NUM32,BIDE,MSDT(3),RINDV
      EL11 = PL(31,J)
      EL22 = PL(32,J)
      NUL12 = PL(37,J)
      NUL21 = PL(38,J)
      VC = 4.0*KV/(PIE*(1.0-KF))
      VC = 1.0/(1.0-SQRT(VC))
      KFB = (1.0-KV)*KF
      KMB = (1.0-KF)*(1.0-KV)
      CF = KFB/KF
      CM = KMB/(1.0-KF)
C      KIES EQUATION
      IF(VCF(1,5) .EQ. 0.0) GO TO 675
      P = SQRT(4.0/PIE)*(KFB**(VCF(1,5)))
      675 IF(VCF(1,5) .NE. 0.0) GO TO 680
      P = SQRT(4.0*KFB/PIE)*VCF(2,5)
      680 A = CM*EM22*(1.0-NUF12*NUF21)/(CF*EF22*(1.0-NUM12*NUM21))
      B = NUM12*CM*EM22*(1.0-NUF12*NUF21)/(CF*EF22*(1.0-NUM12*NJM21))
      S1 = (1.0-(NUL21*P*(NUF12-B)))*(1.0/EL22)*SL22
      S2 = (1.0/EL11)*(P*(NUF12-B)-NUL12)*SL11
      S3 = (1.0/(1.0+P*(A-1.0)))*(S1+S2)
      S4 = (SL22/EL22)-(NUL12*SL11/EL11)
      IF (ABS(S4) - 0.0) 681, 681, 682
      681 MF22 = 1.0
      GO TO 683
      682 MF22 = S3/S4
      IF (MF22 .LT. 1.0) GO TO 684
      GO TO 683
      684 MF22 = 1.0
      683 VMF(1) = MF22*VC
C      DANNIELS EQUATION
      S1 = SQRT(PIE/KFB)
      S1 = (S1-2.0)
      S1 = 0.83*S1*S1-1.35*S1+1.78
      MF22 = S1*(1.0-NUM23*NUM32)*(EL22/EM22)
      MF22 = MF22*VC
      VMF(2) = MF22
C      KIES 1-D MAGNIFICATION FACTOR
      P = SQRT(4.0*KFB/PIE)*VCF(2,5)
      S1 = CM*EM22/(CF*EF22)
      S1 = 1.0-P*(1.0-S1)
      MF22 = 1.0/S1

```

```

FF22 = MF22*VC
VMF(5) = MF22
IF (VCF(1,6) .EQ. 0.0) GO TO 695
P = KFB** (1.0/VCF(1,6))
695 IF (VCF(1,6) .NE. 0.0) GO TO 700
P = SQRT(4.0*KFB/PIE)*VCF(2,6)
700 S1 = (CM*EM12/(CF*EF12))
S3 = 1.0-(P*(1.0-S1))
MF12 = 1.0/S3
IF (VCF(1,7) .EQ. 0.0) GO TO 701
P = KFB** (1.0/VCF(1,7))
701 IF (VCF(1,7) .NE. 0.0) GO TO 702
P = SQRT(4.0*KFB/PIE)*VCF(2,7)
702 S1 = CM*EM23/(CF*EF23)
S3 = 2.0*(1.0-P)+((2.0*P-1.0)*S1)
MF23 = 1.0/S3
VMF(6) = MF12*VC
VMF(7) = MF23*VC
PL(43,J) = VMF(5)
PL(44,J) = VMF(2)
PL(45,J) = VMF(1)
PL(46,J) = VMF(3)
PL(47,J) = VMF(6)
PL(48,J) = VMF(7)
RETURN
END

```

```

SUBROUTINE COMSA(M)
C COMPUTES STRAIN AND STRESSES IN THE LAYERS GIVEN THE PRESCRIBED
C EDGE FORCES, LAYER TEMP. AND CURVATURES
REAL KL12,NS,LV,MS
DIMENSION AIN(3,3),NS(3),RL(3,3),AL(3),FL(3,3),
2 CE(6,6),CEIN(6,6),LV(6),DISV(6),MS(3),
2 TS1(3),TS2(3),SIGL(3),EPSL(3)
LOGICAL TLINP,C SANB,BIDE,RINDV
670 FORMAT(1H1)
680 FORMAT(/)
681 FORMAT(//)
682 FORMAT(//6H DISP.,34X,29H DISPLACEMENT FORCE RELATI0NS,45X,
2 7H FORCES)
682 FORMAT(2X,A6,4X,3E14.4,1X,3E14.4,15X,A6)
684 FORMAT( E12.4,8X,3E14.4,1X,3E14.4,3X,E14.4)
REAL NUF12,NUF23,NUF13,NUF21,NUF32,NUF31,
2 NUL12,NUL23,NUL13,NUL21,NUL32,NUL31,
2 NUM12,NUM23,NUM13,NUM21,NUM32,NUM31,
2 LSC,MLR,NBS,MBS,KVL,KFL,MSDT,MSDT
COMMON
2 EM22,E411,EM23,EM12,NUM21,NUM12,NUM23,
2 EF22,EF11,EF23,EF12,NUF21,NUF12,NUF23,
2 EM32,NUM13,RHOM,ECM(3,3),EM13,VAM(3),AXC(3,3),FLC(3,3),
2 EF33,NUF13,RHDF,ECF(3,3),EF13,VAF(3),
2 SET(2,8),NBS(3,10),PL(71,5),WXX(3),LSC(6),PC(54),CFC(3,3),
2 CHK(3,4),BTA(4),TLINP,DIAF,NFPE,PIE,
2 MBS(3,10),RAC(3,3),DISV1(10,6),
2 CSANB,NPL,NL,MSDT(3),VCF(2,10),NUM32,BIDE,MSDT(3),RINDV
COMMON/GPCOM/RESF(6),DISP(6)
CALL INVA(3,AXC,AIN)
DO 685 I = 1,3
  MS(I) = MBS(I,M)
685 NS(I) = NBS(I,M)
CC=0.0
DO 678 I = 1,3
  DO 688 J = 1,3
    CE(I,J) = AXC(I,J)
    JP3 = J + 3
    IP3 = I + 3
    CE(I,JP3) = CPC(I,J)
    CE(IP3,J) = CPC(I,J)
688 CE(IP3,JP3) = FLC(I,J)
CALL INVA(6,CE,CEIN)
IF (.NCT. RINDV) GO TO 677
DO 675 J = 1,6
  DISV(J) = DISV1(M,J)
  GO TO 695
677 CONTINUE
DO 689 I = 1,3
  LV(I) = NS(I) + MSDT(I)
  IP3 = I + 3
689 LV(IP3) = MS(I) + MSDT(I)
DO 691 I = 1,6
  DISV(I) = 0.0
  DO 691 K = 1,6
    691 DISV(I) = DISV(I) + CEIN(I,K)*LV(K)

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```

695 CONTINUE
  DO 692 I = 1,3
  IP3 = I + 3
692 WXX(I) = DISV(IP3)
  WRITE(6,679)
  WRITE(6,682)
  WRITE(6,680)
  DO 686 I = 1,3
  WRITE(6,680)
686 WRITE(6,683) DISP(I),(CEIN(I,J),J = 1,6),RESF(I)
  WRITE(6,680)
  DO 687 I = 4,6
  WRITE(6,680)
687 WRITE(6,683) DISP(I),(CEIN(I,J),J = 1,6),RESF(I)
  IF (RINDV) GO TO 696
  DO 690 I = 1,6
  DISV(I) = 0.0
  DO 690 J = 1,6
690 DISV(I) = DISV(I) + CEIN(I,J)*LV(J)
  GO TO 698
696 CONTINUE
  CALL INVA(6,CEIN,CEIN)
  DO 697 I = 1,6
  LV(I) = 0.0
  DO 697 J = 1,6
697 LV(I) = LV(I) + CEIN(I,J)*DISV(J)
  CALL INVA(6,CEIN,CEIN)
698 CONTINUE
  WRITE(6,681)
  WRITE(6,682)
  WRITE(6,680)
  DO 693 I = 1,3
  WRITE(6,680)
693 WRITE(6,684) DISV(I),(CEIN(I,J),J = 1,6),LV(I)
  WRITE(6,680)
  DO 694 I = 4,6
  WRITE(6,680)
694 WRITE(6,684) DISV(I), (CEIN(I,J),J = 1,6),LV(I)
C BEGIN I - LOOP
  DO 790 I = 1,NL
  TH = PL(14,I)
  RL(2,2) = COS(TH)*COS(TH)
  RL(1,1) = COS(TH)*COS(TH)
  RL(1,2) = SIN(TH)*SIN(TH)
  RL(2,1) = SIN(TH)*SIN(TH)
  S1 = SIN(2.0*TH)
  RL(2,3) = -0.5*S1
  RL(1,3) = 0.5*S1
  RL(3,1) = -S1
  RL(3,2) = S1
  RL(3,3) = COS(2.0*TH)
  AL(1) = PL(24,I)
  AL(2) = PL(25,I)
  AL(3) = 0.0
  DO 715 J = 1,3
  DO 715 K = 1,3
715 EL(J,K) = 0.0
  EL(1,1) = 1.0/PL(31,I)
  EL(2,2) = 1.0/PL(32,I)

```

```

EL(3,3) = 1.0/PL(36,I)
EL(1,2) = -PL(38,I)/PL(32,I)
EL(2,1) = -PL(37,I)/PL(31,I)
CALL INVA(3,EL,EL)
IF (RINDV) GO TO 699
IF (CC .NE. 0.0) GO TO 699
DO 725 J = 1,3
S1 = C.0
DO 720 K = 1,3
720 S1 = S1+CPC(J,K)*WXX(K)
725 TS1(J) = NS(J)+S1+NSDT(J)
DO 735 J = 1,3
S1 = C.0
DO 730 K = 1,3
730 S1 = S1+AIN(J,K)*TS1(K)
735 TS2(J) = S1-PL(11,I)*WXX(J)
DO 745 J = 1,3
S1 = C.0
DO 740 K = 1,3
740 S1 = S1+RL(J,K)*TS2(K)
745 EPSL(J) = S1
DO 748 J = 1,3
748 TS1(J) = EPSL(J)-(AL(J)*PL(50,I))
DO 755 J = 1,3
S1 = C.0
DO 750 K = 1,3
750 S1 = S1+EL(J,K)*TS1(K)
755 SIGL(J) = S1
GO TO 700
695 CONTINUE
DO 701 J = 1,3
TS1(J) = C.0
701 TS1(J) = TS1(J) + DISV(J) + PL(11,I)*DISV(J+3)
DO 703 J = 1,3
EPLS(J) = C.0
DO 703 K = 1,3
703 EPLS(J) = EPLS(J) + RL(J,K)*TS1(K)
DO 705 J = 1,3
SIGL(J) = C.0
TS2(J) = EPLS(J) - PL(50,I)*AL(J)
DO 705 K = 1,3
705 SIGL(J) = SIGL(J) + EL(J,K)*TS2(K)
700 CONTINUE
C      CONSTRCT LAYER,COMBINED STRESS LIMIT STRENGTH CRITERION
SIGL1 = SIGL(1)
SIGL2 = SIGL(2)
SIGL3 = SIGL(3)
PL1I = PL(1,I)
PL2I = PL(2,I)
IF (ABS(SIGL1) .EQ. 0.0) SIGL1 = .0001
CALL GSMF(SIGL1,SIGL2,SIGL3,1.0,PL1I,PL2I,I)
CALL GLLSC(I)
IF ((SIGL(1)*SIGL(2)) .LT. 0.0) GO TO 765
IF (SIGL(1) .LT. 0.0) GO TO 760
KL12 = BET(1,7)
S1 = PL(51,I)
S2 = PL(54,I)
IF(SIGL(2) .LE. 0.0) GO TO 757
S2 = PL(54,I)

```

```

757 GO TO 780
760 IF (SIGL(1) .GE. 0.0) GO TO 765
    KL12 = BET(2,8)
    S2 = PL(55,I)
    S1 = AMIN1(PL(52,I),PL(53,I))
    GO TO 780
765 IF ((SIGL(1)*SIGL(2)) .GE. 0.0) GO TO 780
    IF (SIGL(1) .LT. 0.0) GO TO 775
    KL12 = BET(1,8)
    S1 = PL(51,I)
    S2 = PL(55,I)
    IF (SIGL(2) .GE. 0.0) GO TO 770
    S2 = PL(55,I)
770 GO TO 780
775 IF (SIGL(1) .GE. 0.0) GO TO 780
    KL12 = BET(2,7)
    S2 = PL(54,I)
    S1 = AMIN1(PL(52,I),PL(53,I))
    GO TO 780
780 KL12 = KL12*PL(61,I)
    S1 = SIGL(1)/S1
    S2 = SIGL(2)/S2
    S3 = SIGL(3)/PL(56,I)
    S4 = (S1*S1)-(KL12*S1*S2)+(S2*S2)+(S3*S3)
    PL(62,I) = 1.0-S4
    S1 = AMIN1(PL(52,I),PL(53,I))
    S2 = PL(51,I)*S1
    S3 = PL(54,I)*PL(55,I)
    S2 = (SIGL(1)*SIGL(1)-SIGL(1)*SIGL(2)+(S1-PL(51,I))*SIGL(1))/S2
    S3 = (SIGL(2)*SIGL(2)+(PL(55,I)-PL(54,I))*SIGL(2))/S3
    PL(71,I) = 1.0-(S2+S3+(SIGL(3)*SIGL(3)/PL(56,I)/PL(56,I)))
    IF (I .LE. 1) GO TO 785
    IM1 = I-1
    S1 = SIN(2.0*TH)-SIN(2.0*PL(14,IM1))
    S3 = COS(2.0*TH)-COS(2.0*PL(14,IM1))
    S3 = TS2(2)-TS2(1)
    S4 = 0.5*(S1*S3+S2*TS2(3))
    PL(70,I) = S4
    PL(63,I) = (PL(60,I)-ABS(S4))/PL(60,I)
785 PL(64,I) = EPSL(1)
    PL(65,I) = EPSL(2)
    PL(66,I) = EPSL(3)
    PL(67,I) = SIGL(1)
    PL(68,I) = SIGL(2)
    PL(69,I) = SIGL(3)
    IF (.NOT. CSANB ) GO TO 790
    IF (I .NE. 2) GO TO 795
790 CONTINUE
C     END I-LOOP
     GO TO 805
795 DO 800 I = 62,NPL
     DO 800 J = 3,NL,2
     PL(I,J) = PL(I,1)
     JP1 = J+1
     IF (JP1 .GT. NL) GO TO 800
     PL(I,JP1) = PL(I,2)
800 CONTINUE
805 CONTINUE
     RETURN
     END

```

## APPENDIX C

### SAMPLE CASES

#### Unidirectional Composite

THORNEL-50/EPOXY

```

NL,NPL,NPC,NPPE,NLC
 8    71    54 1420   1

EF11,EF22,EF33,NUF12,NUF23,NUF13,EF12,EF23,EF13,EM11,EM22,EM33,NUM12,NUM23,NUM13,EM12,EM23,EM13
 0.5000E 03  0.1000E 07  0.1000E 07  0.2000E 03  0.2500E 03  0.2000E 00  0.1300E 07  0.7000E 06  0.1300F 07  0.5700E 05
 0.5700E 06  0.5700E 06  0.3600E 00  0.3600E 03  0.3600E 00  0.          0.          0.          0.          0.

VCF
 0.4000E 01  0.2000E 01  0.4000E 01  0.2000E 01  0.          0.          0.          0.2356E 01  0.          0.
 0.          0.          0.          0.1000E 01  0.1000E 01  0.1000E 01  0.          0.          0.

VAF
 -0.5500E-06  0.5600E-05  0.5600E-05
VAM
 0.4280E-04  0.4280E-04  0.4280E-04
CHK
 0.5800E 03  0.5800E 02  0.5800E 02  0.1700E 00  0.1250E 01  0.1250E 01  0.1250E 01  0.2500E 00  0.          0.
 0.          0.2250E 00
BTA
 0.1000E 01  0.1000E 01  0.1050E 01  0.1050E 01
PIE
 0.31416E 01

TL INP
 F

CSANB
 F

BIDE
 F

RINDV
 F

THCS,RHDF,RHCM,DIAF
 0.          0.5900E-01  0.44300E-01  0.26000E-03
KVL
 0.          0.          0.          0.          0.          0.          0.          0.
KFL
 0.5000E 00  0.5000F 00
THLC
 0.          0.          0.          0.          0.          0.          0.          0.
TL
 0.8C500E-02  0.80500E-02  0.80000E-02  0.80000E-02  0.80500E-02  0.80500E-02  0.80000E-02
PTEMP
 -0.3000E 03 -0.3000E 03

BET
 C.8300E 00  0.1000E 01  0.2600E 00  0.2700E 03  0.1700E 03  0.1650E 02  0.1000E 01  0.1000E 01  0.4550E-01  0.1330E 01
 0.5000E 00  0.1330E 02  0.3190E 05  0.1000E 01  0.1000E 01  0.1000E 01

LSC
 0.2300E 06  0.2100E 05  0.2000E-01  0.5000E-01  0.4500E-01  0.4500E-01

NBS
 0.5000E 04  0.          0.
MBS
 0.5000E 02  0.          0.

DISV1
 0.          0.          0.          0.          0.          0.

```

#### 3-D COMPOSITE STRAIN STRESS TEMPERATURE RELATIONS - STRUCTURAL AXES

0.3955E-07	-0.9941E-08	-0.9941E-08	0.	0.	0.	-0.6138E-07
-0.9941E-08	0.1042E-05	-0.4266E-06	-0.	-0.	-0.	0.2334E-04
-0.9941E-08	-0.4266E-06	0.1042E-05	0.	0.	0.	0.2334E-04
0.	0.	0.	0.2937E-05	0.	0.	0.
0.	0.	0.	0.	0.2937E-05	0.	0.
0.	0.	0.	0.	0.	0.1578E-05	0.

3-D COMPOSITE STRESS STRAIN RELATIONS - STRUCTURAL AXES

0.2549E 08	0.4118E 06	0.4118E 06	-0.	-0.	-0.
0.4118E 06	0.1160E 07	0.4787E 06	-0.	-0.	0.
0.4118E 06	0.4787E 06	0.1160E 07	-0.	-0.	-0.
-0.	-0.	-0.	0.3405E 06	-0.	-0.
-0.	-0.	-0.	-0.	0.3405E 06	-0.
-0.	0.	-0.	-0.	-0.	0.6339E 06

COMPOSITE PROPERTIES - VALID ONLY FOR CONSTANT TEMPERATURE THROUGH THICKNESS  
 LINES 1 TO 21 3-D COMPOSITE PROPERTIES ABOUT MATERIAL AXES

LINES 33 TO 54 2-D COMPOSITE PROPERTIES ABOUT STRUCTURAL AXES

1	RHOC	0.5165E-01
2	TC	C.6400E-01
3	CC11	0.2549E 08
4	CC12	0.4118E 06
5	CC13	C.4118E 06
6	CC22	0.1160E 07
7	CC23	0.4787E 06
8	CC33	C.1160E 07
9	CC44	0.3405E 06
10	CC55	0.3405E 06
11	CC66	C.6339E 06
12	CTE11	-C.6138E-07
13	CTE22	0.2334E-04
14	CTE33	0.2334E-04
15	HK11	0.2906E 03
16	HK22	0.3715E 01
17	HK33	0.3715E 01
18	HHC	0.2043E 00
19	EC11	0.2528E 08
20	EC22	0.9597E 06
21	EC33	C.9597E 06
22	EC23	0.3405E 06
23	EC31	C.3405E 06
24	EC12	0.6339E 06
25	NUC12	0.2514E 00
26	NUC21	0.9541E-02
27	NUC13	0.2514E 00
28	NUC31	C.9541E-02
29	NUC23	0.4094E 00
30	NUC32	0.4094E 00
31	ZCGC	0.3200E-01
32	B2DEC	0.
33	CC11	0.2535E 08
34	CC12	0.2418E 06
35	CC13	-0.
36	CC22	C.9620E 06
37	CC23	0.
38	CC33	C.6339E 06
39	EC11	0.2528E 08
40	EC22	C.9597E 06
41	EC12	0.6339E 06
42	NUC12	0.2514E 00
43	NUC21	0.9541E-02
44	CSN13	-0.
45	CSN31	-0.
46	CSN23	-0.
47	CSN32	0.
48	CTE11	-0.6138E-07
49	CTE22	0.2334E-04
50	CTE12	C.
51	HK11	0.2906E 03
52	HK22	0.3715E 01
53	HK12	-0.
54	HHC	0.2043E 00

FORCES				FORCE DISPLACEMENT RELATIONS				DISPL	THERMAL FORCES
NX	0.1622E 07	0.1548E 05	-0.	0.2441E-03	0.1907E-05	-0.	UX	-0.7849E 02	
NY	0.1548E 05	0.6157E 05	0.	0.2384E-05	0.5722E-05	0.	VX	-0.4308E 03	
NXY	-0.	0.	0.4057E 05	-0.	0.	0.5722E-05	VXPY	-0.	
MX	0.2441E-03	0.2384E-05	-0.	0.5537E 03	0.5283E 01	-0.	WXX	-0.1490E-07	
MY	0.1907E-05	0.5722E-05	0.	0.5283E 01	0.2102E 02	0.	WYY	-0.5950E-07	
MXY	-0.	0.	0.5722E-05	-0.	0.	0.1385E 02	WXY	-0.	

REDUCED BENDING RIGIDITIES

0.55369E 03	0.52825E 01	-0.	0.52825E 01	0.21016E 02	0.	-0.	0.	0.13847E 02
-------------	-------------	-----	-------------	-------------	----	-----	----	-------------

REDUCED STIFFNESS MATRIX  
 $0.16221E\ 07$   $0.10476E\ 05$   $-0.$   $0.15476E\ 05$   $0.61569E\ 05$   $0.$   $-0.$   $0.$   $0.$   $0.40558E\ 05$

DISP.								DISPLACEMENT FORCE RELATIONS			FORCES	
UX	0.5180E-06	-0.1553E-06	0.		-0.2723E-12	0.5466E-13	-0.				NX	
VX	-0.1553E-06	0.1628E-04	-0.		0.4064E-13	-0.4429E-11	0.				NY	
VXP <sub>UY</sub>	-0.	0.	0.2465E-04		0.	-0.	-0.	-0.1019E-10			NXY	
WXX	-0.2723E-12	0.5466E-13	-0.		0.1810E-02	-0.4551E-03	0.				MX	
WYY	0.4064E-13	-0.4429E-11	0.		-0.4551E-03	0.4770E-01	-0.				MY	
WXY	0.	0.	-0.1019E-10		0.	0.	0.	0.7222E-01			MXY	

DISP.								DISPLACEMENT FORCE RELATIONS			FORCES	
0.3108E-02	0.6130E-06	-0.1553E-06	0.		-0.2723E-12	0.5466E-13	-0.				0.4922E-04	
-0.7778E-02	-0.1553E-06	0.1628E-04	-0.		0.4064E-13	-0.4429E-11	0.				-0.4308E-03	
0.	-0.	0.	0.2465E-04		0.	-0.	-0.	-0.1019E-10			-0.	
0.9052E-01	-0.2723E-12	0.5466E-13	-0.		0.1810E-02	-0.4551E-03	0.				0.5000E-02	
-0.2275E-01	0.4064E-13	-0.4429E-11	0.		-0.4551E-03	0.4770E-01	-0.				-0.5960E-07	
-0.	0.	0.	-0.1019E-10		0.	0.	0.	0.7222E-01			-0.	

FOR THIS CASE NHSE(X,Y,XY-M) IS 5000. 0. 0.

FOR THIS CASE 4BS(X,Y,XY-M) IS 50. 0. 0.

LAYER PROPERTIES, ROWS=PROPERTY, COLUMNS=LAYER

1	KV	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	KF	0.5000E-09										
3	KFB	0.5000E-09										
4	KM	0.3000E-09	0.5000E-09									
5	KMH	0.5000E-09										
6	RFL	0.5155E-01										
7	TL	0.3000E-02										
8	Delta	0.6585E-04										
9	frc	-0.6000E-12	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
10	Z3	0.4000E-02	-0.1200E-01	0.2000E-01	0.2800E-01	0.3600E-01	0.4400E-01	0.5200E-01	0.6000E-01	0.6800E-01	0.7600E-01	0.8400E-01
11	ZG	-0.2800E-01	-0.2000E-01	-0.1200E-01	-0.4000E-02	0.4000E-02	0.1200E-01	0.2000E-01	0.2800E-01	0.3600E-01	0.4400E-01	0.5200E-01
12	THCS	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
13	THLC	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
14	THLS	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
15	SC11	0.2549E-04	0.2549E-08									
16	SC12	0.4118E-06										
17	SC13	0.4118E-06										
18	SC22	0.1160E-07										
19	SC23	0.4797E-06										
20	SC33	0.1160E-07										
21	SC44	0.3405E-06										
22	SL59	0.3405E-06										
23	SL65	0.6339E-06										
24	CTE11	-0.6138E-07										
25	CTE22	0.2334E-04										
26	CTE33	0.2334E-04										
27	HK11	0.2906E-03										
28	HK22	0.3715E-01										
29	HK33	0.3715E-01										
30	HCL	0.2043E-09										
31	EL11	0.2528E-08										
32	EL22	0.9597E-05	0.9597E-06									
33	EL33	0.9597E-06										
34	GL23	0.3405E-06										
35	GL13	0.6339E-06										
36	GL12	0.6339E-06										
37	NUL12	0.2514E-00										
38	NUL21	0.9541E-02										
39	NUL13	0.2514E-00										
40	NUL31	0.9541E-02										

41	NUL23	0.4094E 00									
42	NUL32	0.4094E 00									
43	SMFK22	0.1522E 01									
44	SMFD22	0.1918E 01									
45	SMFS22	0.1537E 01									
46	SMFC22	-0.0000E-19									
47	SMFS12	0.3024E 01									
48	SMFS23	0.1396E 01									
49	ILMFC	-0.0000E-19	0.7060E 02								
50	TEMPO	-0.3000E 03									
51	LSC11T	0.9676E 05									
52	LSC11C	0.5333E 05									
53	LSC11D	0.6578E 05									
54	LSC22T	0.3248E 04									
55	LSC22G	0.1561E 05									
56	LSC12	0.2547E 04									
57	LSC23	0.1866E 04									
58	LSCC23	-0.0000E-19									
59	LSCC13	-0.0000E-19									
60	LSCDF	-0.0000E-19	0.1052E-01								
61	KL12A8	0.1371E 01									
62	MDE1E	0.9739E 00	0.8879E 00	0.7254E 00	0.4913E 00	0.1855E 00	-0.1918E 00	-0.6408E 00	-0.1161E 01	-0.1161E 01	-0.1161E 01
63	RELROT	-0.0000E-19	0.1000E 01								
64	EPS11	0.5736E-03	0.1298E-02	0.2022E-02	0.2746E-02	0.3470E-02	0.4194E-02	0.4919E-02	0.5643E-02	0.6372E-02	0.7141E-02
65	EPS22	-0.7141E-02	-0.7323E-02	-0.7595E-02	-0.7687E-02	-0.7869E-02	-0.8051E-02	-0.8233E-02	-0.8415E-02	-0.8597E-02	-0.8780E-02
66	EP S12	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
67	SIG11	0.14C7E 05	0.3239E 05	0.5077E 05	0.6901E 05	0.8732E 05	0.1056E 06	0.1239E 05	0.1423E 06	0.1616E 06	0.1809E 06
68	SIG22	0.4826E-03	0.4845E-03	0.4692E-03	0.4654E-03	0.5188E-03	0.4578E-03	0.5188E-03	0.4578E-03	0.4425E-03	0.4425E-03
69	SIG12	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
70	DELFI	-0.0000E-19	0.	0.	0.	0.	0.	0.	0.	0.	0.
71	HFC	0.1080E 01	0.1069E 01	0.9285E 00	0.6579E 00	0.2572E 00	-0.2734E 00	-0.9339E 00	-0.1724E 01	-0.1724E 01	-0.1724E 01

### Angle Ply Composite

THORNEL-5C/EPoxy

NL,NPL,NPC,NPE,NLC

8 71 54 1420 1

EF11,EF22,EF23,NUF12,NUF23,NUF13,EF12,EF23,EF13,EM11,EM22,EM33,NUM12,NUM23 NUM13,EM12,EM23,EM13  
 0.5000E 03 -0.1700E 07 0.1000E 07 0.2000E 03 0.2500E 03 0.2000E 00 0.1300E 07 0.7000E 06 0.1300E 07 0.5700E 06

0.5700E 06 0.5700E 06 0.3690E 00 0.3600E 00 0.3600E 00 0.

VCF 0.4000E 01 0.2000E 01 0.4000E 01 0.2000E 01 0. 0. 0. 0. 0.2356E 01 0. 0.

0. 0. 0. 0. 0.1000E 01 0.1000E 01 0.1000E 01 0. 0. 0.

VAF -0.5500E-06 0.5600E-05 0.5500E-05

VAM 0.4280E-04 0.4280E-04 0.4280E-04

CHK 0.5800E 03 0.5800E 02 0.5300E 02 0.1700E 00 0.12500E 01 0.12500E 01 0.12500E 01 0.2500E 00 0.

0. 0. 0.2250E 00

DTA 0.1000E 01 0.1000E 01 0.10500E 01 0.10500E 01

PIE 0.3141E 01

TL INP F

CSAN b F

BICE F

RINDV F

THCS,RHOF,RHCM,DIAF 0. 0.5900E-01 0.4430E-01 0.2600E-03

KVL 0. 0. 0. 0. 0. 0. 0. 0.

KFL 0.5000E 01 0.5000E 00 0.5000E 00 0.5000E 00 0.5000E 00 0.5000E 00 0.5000E 00 0.5000E 00

THLC 0.3000E 02 -0.3000E 02 0.3000E 02 -0.3000E 02 -0.3000E 02 0.3000E 02 -0.3000E 02 0.3000E 02

TL 0.8050E-02 0.8050E-02 0.8000E-02 0.8000E-02 0.8000E-02 0.8050E-02 0.8050E-02 0.8000E-02

PTEMP -0.3000E 03 -0.3000E 03 -0.3000E 03 -0.3000E 03 -0.3000E 03 -0.3000E 03 -0.3000E 03

BET C.8300E 00 0.1000E 01 0.2600E 00 0.2700E 00 0.1700E 00 0.1650E 02 0.1000E 01 0.1000E 01 0.46500E-01 0.1000E 01

0.5000E 00 0.1330E 02 0.3190E 05 0.1300E 01 0.1000E 01 0.1000E 01

LSC C.2300E 06 0.2100E 05 0.2000E-01 0.5000E-01 0.45000E-01 0.45000E-01

NBS 0.5000E 04 0. 0.

MBS 0.5000E 02 0. 0.

DISV1 0. 0. 0. 0. 0. 0.

3-D COMPOSITE STRAIN STRESS TEMPERATURE RELATIONS - STRUCTURAL AXES

0.1430E-06	-0.2449E-06	0.4471E-07	0.	0.	0.	-0.3131E-05
-0.2449E-06	0.7909E-06	-0.2246E-06	-0.	-0.	-0.	0.1199E-04
0.4471E-07	-0.2246E-06	0.9353E-06	0.	0.	0.	0.2933E-04
0.	0.	0.	0.2937E-05	0.	0.	-0.
0.	0.	0.	0.	0.2937E-05	0.	-0.
0.	0.	0.	0.	0.	0.2000E-06	-0.

3-D COMPOSITE STRESS STRAIN RELATIONS - STRUCTURAL AXES

0.1504E 08	0.4779E 07	0.4285E 06	-0.	-0.	0.	
0.4779E 07	0.2875E 07	0.4620E 06	-0.	-0.	0.	
0.4285E 06	0.4620E 06	0.1160E 07	-0.	-0.	-0.	
-0.	-0.	-0.	0.3405E 06	-0.	-0.	
-0.	-0.	-0.	-0.	0.3405E 06	-0.	
0.	0.	-0.	-0.	-0.	0.5001E 07	

COMPOSITE PROPERTIES - VALID ONLY FOR CONSTANT TEMPERATURE THROUGH THICKNESS  
 LINES 1 TO 31 3-D COMPOSITE PROPERTIES ABOUT MATERIAL AXES

LINES 33 TO 54 2-D COMPOSITE PROPERTIES ABOUT STRUCTURAL AXES

1	RHUL	0.5165E+01
2	TC	0.640CE-01
3	CC11	0.1504E 08
4	CC12	0.4779E 07
5	CC13	0.4285E 06
6	CC22	0.2875E 07
7	CC23	0.4620E 06
8	CC33	0.1160E 07
9	CC44	0.3405E 06
10	CC55	0.3405E 06
11	CC66	0.5001E 06
12	CTE11	-0.3131E-05
13	CTE22	0.1199E-04
14	CTE33	0.2933E-04
15	HK11	0.2189E 03
16	HK22	0.7544E 02
17	HK33	0.3715E 01
18	HHC	0.2043E 00
19	EC11	0.5792E 07
20	EC22	0.1264E 07
21	EC33	0.1069E 07
22	EC23	0.3405E 06
23	EC31	0.3405E 06
24	EC12	0.5001E 07
25	NUC12	0.1712E 01
26	NUC21	0.3096E 00
27	NUC13	-0.3126E 00
28	NUC31	-0.4790E-01
29	NUC23	0.2839E 00
30	NUC32	0.2401E 00
31	ZCGC	0.3200E-01
32	B2DEC	0.
33	CC11	0.1498E 08
34	CC12	0.4608E 07
35	CC13	0.
36	CC22	0.2691E 07
37	CC23	0.
38	CC33	0.5601E 07
39	EC11	0.6992E 07
40	EC22	0.1264E 07
41	EC12	0.5001E 07
42	NUC12	0.1712E 01
43	NUC21	0.3096E 00
44	CSN13	-0.
45	CSN31	-0.
46	CSN23	-0.
47	CSN32	0.
48	CTE11	-0.3131E-05
49	CTE22	0.1199E-04
50	CTE12	-0.
51	HK11	0.2189E 03
52	HK22	0.7544E 02
53	HK12	-0.
54	HHC	0.2043E 00

FORCES	FORCE DISPLACEMENT RELATIONS						DISPL	THERMAL FORCES
NX	0.9525E 06	0.2949E 06	0.	0.1221E-03	0.4578E-04	0.1068E-03	UX	-0.1666E 03
NY	0.2949E 06	0.1722E 06	0.	0.4578E-04	0.2289E-04	0.3815E-04	VX	-0.3427E 03
NXY	0.	0.	0.3200E 06	0.1068E-03	0.3815E-04	0.3052E-04	VXPY	0.
MX	0.1221E-03	0.4578E-04	0.1068E-03	0.3251E 03	0.1007E 03	0.6390E 02	WXX	-0.2235E-07
MY	0.4578E-04	0.2289E-04	0.3815E-04	0.1007E 03	0.5879E 02	0.2260E 02	WYY	-0.2980E-07
MXY	0.1068E-03	0.3815E-04	0.3052E-04	0.6390E 02	0.2260E 02	0.1092E 03	WXY	0.2980E-07

#### REDUCED BENDING REGIDITIES

0.32513E 03 0.10067E 03 0.63900E 02 0.10067E 03 0.58793E 02 0.22595E 02 0.63900E 02 0.22595E 02 0.10924E 03

#### REDUCED STIFFNESS MATRIX

0.95252E 06 0.29494E 06 -0.49233E-10 0.29494E 06 0.17225E 06 -0.19281E-10 -0.49233E-10 -0.19281E-10 0.32003E 06

DISP.	DISPLACEMENT FORCE RELATIONS						FORCES
UX	0.2235E-05	-0.3827E-05	0.1132E-21	-0.3456E-12	0.6409E-12	-0.7792E-12	NX
VX	-0.3827E-05	0.1236E-04	0.1559E-21	0.6225E-12	-0.2756E-11	-0.3680E-12	NY
VXPY	0.1132E-21	0.1559E-21	0.3125E-05	-0.8006E-12	-0.5443E-12	-0.2920E-12	NXY
WXX	-0.3456E-12	0.6225E-12	-0.8006E-12	0.6830E-02	-0.1104E-01	-0.1712E-02	MX
WYY	0.6409E-12	-0.2756E-11	-0.5443E-12	-0.1104E-01	0.3631E-01	-0.1055E-02	MY
WXY	-0.7792E-12	-0.3680E-12	-0.2920E-12	-0.1712E-02	-0.1055E-02	0.1037E-01	MXY

DISP.	DISPLACEMENT FORCE RELATIONS						FORCES
0.1211E-01	0.2235E-05	-0.3827E-05	0.1132E-21	-0.3456E-12	0.6409E-12	-0.7792E-12	0.4833E 04
-0.2273E-01	-0.3827E-05	0.1236E-04	0.1559E-21	0.6225E-12	-0.2756E-11	-0.3680E-12	-0.3427E 03
-0.4003E-10	0.1132E-21	0.1559E-21	0.3125E-05	-0.8006E-12	-0.5443E-12	-0.2920E-12	0.
0.3415E 00	-0.3456E-12	0.6225E-12	-0.8006E-12	0.6830E-02	-0.1104E-01	-0.1712E-02	0.5000E 02
-0.5518E 00	0.6409E-12	-0.2756E-11	-0.5443E-12	-0.1104E-01	0.3631E-01	-0.1055E-02	-0.2980E-07
-0.8561E-01	-0.7792E-12	-0.3680E-12	-0.2920E-12	-0.1712E-02	-0.1055E-02	0.1037E-01	0.2980E-07

FOR THIS CASE NBS(X,Y,XY-M) IS 5000. 0. 0.

FOR THIS CASE MBS(X,Y,XY-M) IS 50. 0. 0.

#### LAYER PROPERTIES, ROWS-PROPERTY, COLUMNS-LAYER

1	KV	0.	0.	0.	0.	0.	0.	0.
2	KF	0.5000E 00						
3	KFB	0.5000E 00						
4	KM	0.5000E 00						
5	KMB	0.5000E 00						
6	RHOL	0.5165E-01						
7	TL	0.8000E-02						
8	DELT A	0.6586E-04						
9	ILDC	-0.0000E-19	0.	0.	0.	0.	0.	0.
10	ZB	0.4000E-02	0.1200E-01	0.2003E-01	0.2800E-01	0.3600E-01	0.4400E-01	0.5200E-01
11	ZGC	-0.2800E-01	-0.2000E-01	-0.1203E-01	-0.4000E-02	0.4000E-02	0.1200E-01	0.2000E-01
12	THCS	0.	0.	0.	0.	0.	0.	0.
13	THLC	0.5236E 00	-0.5236E 00	0.5236E 00	-0.5236E 00	-0.5236E 00	0.5236E 00	-0.5236E 00
14	THLS	0.5236E 00	-0.5236E 00	0.5236E 00	-0.5236E 00	0.5236E 00	-0.5236E 00	0.5236E 00
15	SC11	0.2549E 08						
16	SC12	0.4118E 06						
17	SC13	0.4118E 06						
18	SC22	0.1160E 07						
19	SC23	0.4787E 06						

20	SC33	0.1160E 07								
21	SC44	0.3405E 06								
22	SC55	0.3405E 06								
23	SC66	0.6339E 06								
24	CTE11	-0.6138E-07								
25	CTE22	0.2334E-04								
26	CTE33	0.2334E-04								
27	HK11	0.2906E 03								
28	HK22	0.3715E 01								
29	HK33	0.3715E 01								
30	HCL	0.2043E 00								
31	EL11	0.2528E 08								
32	EL22	0.9597E 06								
33	EL33	0.9597E 06								
34	GL23	0.3405E 06								
35	GL13	0.6339E 06								
36	GL12	0.6339E 06								
37	NUL12	0.2514E 00								
38	NUL21	0.9541E-02								
39	NUL13	0.2514E 00								
40	NUL31	0.9541E-02								
41	NUL23	0.4094E 00								
42	NUL32	0.4094E 00								
43	SWMK22	0.1522E 01								
44	SMFD22	0.1918E 01								
45	SMFS22	0.1344E 01	0.1344E 01	0.1408E 01	0.1408E 01	0.1408E 01	0.1399E 01	0.1399E 01	0.1399E 01	0.1399E 01
46	SMFC22	-0.0000E-19								
47	SMFS12	0.3024E 01								
48	SMFS23	0.1396E 01								
49	ILMFC	-0.0000E-19	0.7060E 02	0.7360E 02	0.7060E 02					
50	TEMPD	-0.3000E 03								
51	LSC11T	0.9676E 05								
52	LSC11C	0.5333E 05								
53	LSC11D	0.6578E 05								
54	LSC22T	0.3714E 04	0.3714E 04	0.3544E 04	0.3544E 04	0.3564E 04	0.3564E 04	0.3572E 04	0.3568E 04	0.3575E 04
55	LSC22C	0.1788E 05	0.1788E 05	0.1704E 05	0.1713E 05	0.1714E 05	0.1714E 05	0.1717E 05	0.1715E 05	0.1719E 05
56	LSC12	0.2547E 04								
57	LSC23	0.1866E 04								
58	LSCC23	-0.0000E-19								
59	LSCC13	-0.0000E-19								
60	LSCDF	-0.0000E-19	0.1052E-01							
61	KL12Ab	0.1371E 01								
62	MUE1E	-0.2387E 01	-0.1400E 02	-0.2529E 02	-0.4584E 02	-0.6868E 02	-0.1003E 03	-0.1282E 03	-0.1774E 03	-0.1774E 03
63	RELROT	-0.0000E-19	0.9050E 00	0.2757E 00	0.2131E 00	0.9518E 00	-0.3178E 01	-0.9446E 01	-0.3204E 01	-0.3204E 01
64	EPS11	0.1132E-02	0.2974E-03	0.2429E-02	0.2781E-02	0.4023E-02	0.4375E-02	0.6506E-02	0.5572E-02	0.5572E-02
65	EPS22	-0.5860E-02	-0.6708E-02	-0.1052E-01	-0.1256E-01	-0.1545E-01	-0.1752E-01	-0.2133E-01	-0.2218E-01	-0.2218E-01
66	EPS12	-0.7315E-02	0.1555E-01	-0.2338E-01	0.2725E-01	0.3310E-01	-0.3397E-01	0.4479E-01	-0.5303E-01	-0.5303E-01
67	SIG11	0.2787E 05	0.7346E 04	0.6117E 05	0.4917E 05	0.1001E 06	0.1084E 06	0.1619E 06	0.1398E 06	0.1398E 06
68	SIG22	0.1363E 04	0.3495E 03	-0.2804E 04	-0.4677E 04	-0.7190E 04	-0.9362E 04	-0.1222E 05	-0.1323E 05	-0.1323E 05
69	SIG12	-0.4637E 04	0.9862E 04	-0.1292E 05	0.1727E 05	0.2098E 05	-0.2534E 05	0.2839E 05	-0.3362E 05	-0.3362E 05
70	DELF1	-0.0000E-19	-0.4159E-03	-0.7617E-02	-0.1276E-01	0.2053E-01	-0.4394E-01	0.1099E 00	-0.9582E-01	-0.9582E-01
71	FFC	-0.2542E 01	-0.1402E 02	-0.2445E 02	-0.4472E 02	-0.6733E 02	-0.9883E 02	-0.1271E 03	-0.1761E 03	-0.1761E 03

### Angle Ply Pseudoisotropic Composite

THORNEL-50/EPOXY

NL	,NPL,NPC,NFPE,NLC									
8	71	54	1420	1						
EF11,EF22,EF23,NUF12,NUF23,NUF13,EF12,EF23,EF13,EM11,EM22,EM33,NUM12,NUM23,NUM13,EM12,EM23,EM13										
0.50000E 08	0.10000E 07	0.10000E 07	0.20000E 00	0.25000E 00	0.20000E 00	0.13000E 07	0.76000E 06	0.13000E 07	0.57000E 06	
0.57000E 06	0.57000E 06	0.36000E 00	0.36000E 00	0.36000E 00	0.	0.	0.	0.	0.	
VCF										
0.40000E 01	0.20000E 01	0.40000E 01	0.20000E 01	0.	0.	0.	0.	0.	0.	
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	
VAF	-0.55000E-06	0.56000E-05	0.56000E-05							
VAM	0.42800E-04	0.42800E-04	0.42800E-04							
CHK	0.58000E 03	0.58000E 02	0.58000E 02	0.17000E 00	0.12500E 01	0.12500E 01	0.12500E 01	0.25000E 00	0.	
0.	0.22500E 00									
BTA	0.10000E 01	0.10000E 01	0.10500E 01	0.10500E 01						
PIE	0.31416E 01									
TL INP	F									
CSANB	F									
BIDE	F									
RINDV	F									
THCS,RHDF,RHCM,DIAP										
0.	0.59000E-01	0.44300E-01	0.26000E-03							

KVL	0.	0.	0.	0.	0.	0.	0.	0.	0.
KFL	0.50000E 00								
THLC	0.	0.45000E 02	-0.45000E 02	0.90000E 02	0.90000E 02	-0.45000E 02	0.45000E 02	0.	
TL	0.80500E-02	0.80500E-02	0.80000E-02	0.80000E-02	0.80000E-02	0.80500E-02	0.80500E-02	0.80000E-02	
PTEMP	-0.30000E 03								
BET	0.83000E 00	0.10000E 01	0.26000E 00	0.27000E 00	0.17000E 03	0.16500E 02	0.10000E 01	0.10000E 01	0.46500E-01
LSC	0.23000E 06	0.21000E 05	0.20000E-01	0.50000E-01	0.45000E-01	0.45000E-01			
NBS	0.50000E 04	0.	0.						
MBS	0.50000E 02	0.	0.						
DISV1	0.	0.	0.	0.	0.	0.			

### 3-D COMPOSITE STRAIN STRESS TEMPERATURE RELATIONS - STRUCTURAL AXES

$0.1078E-06$	$-0.3319E-07$	$-0.2866E-07$	$0.$	$0.$	$-0.1893E-12$	$0.9901E-06$
$-0.3319E-07$	$0.1078E-06$	$-0.2866E-07$	$-0.$	$-0.$	$0.6595E-12$	$0.9901E-06$
$-0.2866E-07$	$-0.2866E-07$	$0.8844E-36$	$0.$	$0.$	$-0.1954E-12$	$0.3219E-04$
$-0.$	$0.$	$-0.$	$0.2937E-05$	$0.$	$0.$	$0.$
$-0.$	$0.$	$-0.$	$0.$	$0.2937E-05$	$0.$	$0.$
$-0.1893E-12$	$0.6595E-12$	$-0.1954E-12$	$0.$	$0.$	$0.2821E-06$	$0.1097E-10$

### 3-D COMPOSITE STRESS STRAIN RELATIONS - STRUCTURAL AXES

0.1041E 08	0.3323E 07	0.4452E 06	-0.	-0.	-0.4730E 00
0.3323E 07	0.1041E 08	0.4452E 06	-0.	-0.	-0.2181E 02
0.4452E 06	0.4452E 06	0.1160E 07	-0.	-0.	0.6121E-01
-0.	-0.	-0.	0.3405E 06	-0.	-0.
-0.	-0.	-0.	-0.	0.3405E 06	-0.
-0.4730E 00	-0.2181E 02	0.6121E-01	-0.	-0.	0.3545E 07

**COMPOSITE PROPERTIES - VALID ONLY FOR CONSTANT TEMPERATURE THROUGH THICKNESS**

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LINES 1 TO 31 3-D COMPOSITE PROPERTIES ABOUT MATERIAL AXES
LINES 33 TO 54 2-D COMPOSITE PROPERTIES ABOUT STRUCTURAL AXES

1 RHD C 0.5165E-01
2 TC C 0.6400E-01
3 CC11 C 0.1041E 08
4 CC12 C 0.3323E 07
5 CC13 C 0.4452E 06
6 CC22 C 0.1041E 08
7 CC23 C 0.4452E 06
8 CC33 C 0.1160E 07
9 CC44 C 0.3405E 06
10 CC55 C 0.3405E 06
11 CC66 C 0.3545E 07
12 CTE11 C 0.9901E-06
13 CTE22 C 0.9901E-06
14 CTE33 C 0.3219E-04
15 HK11 C 0.1472E 03
16 HK22 C 0.1472E 03
17 HK33 C 0.3715E 01
18 HHC C 0.2043E 00
19 EC11 C 0.9273E 07
20 EC22 C 0.9273E 07
21 EC33 C 0.1131E 07
22 EC23 C 0.3405E 06
23 EC31 C 0.3405E 06
24 EC12 C 0.3545E 07
25 NUC12 C 0.3078E 00
26 NUC21 C 0.3078E 00
27 NUC13 C 0.2658E 00
28 NUC31 C 0.3241E-01
29 NUC23 C 0.2658E 00
30 NUC32 C 0.3241E-01
31 ZCGC C 0.3200E-01
32 B2DEC C 0.
33 CC11 C 0.1024E 08

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34	CC12	0.3153E 07
35	CC13	-0.4197E 00
36	CC22	0.1924E 08
37	CC23	-0.2182E 02
38	CC33	0.3545E 07
39	EC11	0.472E 07
40	EC22	0.9272E 07
41	EC12	0.3545E 07
42	NUC12	0.3078E 00
43	NUC21	0.3978E 00
44	CSN13	0.1755E-05
45	CSN31	0.5725E-06
46	CSN23	-0.5113E-05
47	CSN32	-0.2337E-05
48	CTE11	0.9901E-06
49	CTE22	0.3901E-06
50	CTE12	0.1097E-10
51	HK11	0.1472E 03
52	HK22	0.1472E 03
53	HK12	0.2794E-03
54	HHC	0.2044E 00

FORCES	FORCE DISPLACEMENT RELATIONS						DISPL	THERMAL FORCES
NX	0.6555E 06	0.2018E 06	-0.3076E-01	0.3652E-03	0.1955E-04	0.2289E-04	UX	-0.2546E 03
NY	0.2018E 06	0.6555E 06	-0.1396E 01	0.2861E-04	-0.1087E-03	0.2289E-04	VX	-0.2546E 03
NXY	-0.3076E-01	-0.1396E 01	0.2269E 06	0.2289E-04	0.2289E-04	0.3052E-04	VXPY	-0.3226E-03
MX	0.3662E-03	0.2861E-04	0.2289E-04	0.3855E 03	0.5695E 02	0.2497E 02	WXX	0.1490E-07
MY	0.1955E-04	-0.1087E-03	0.2289E-04	0.5695E 02	0.8587E 02	0.2497E 02	WYY	-0.7451E-07
MXY	0.2289E-04	0.2289E-04	0.3052E-04	0.2497E 02	0.2497E 02	0.6552E 02	WXY	0.1118E-07

#### REDUCED BEARING RIGIDITIES

0.3855E 03 0.56952E 02 0.24969E 02 0.56952E 02 0.85868E 02 0.24969E 02 0.24969E 02 0.24969E 02 0.65517E 02

REDUCED STIFFNESS MATRIX  
 $0.65554E 06 \quad 0.20179E 06 \quad -0.30762E-01 \quad 0.20179E 05 \quad 0.65554E 06 \quad -0.13965E 01 \quad -0.30762E-01 \quad -0.13965E 01 \quad 0.22688E 06$

DISP.	DISPLACEMENT FORCE RELATIONS						FORCES
UX	0.1685E-05	-0.5187E-06	-0.2964E-11	-0.1567E-11	-0.6338E-13	0.2138E-12	NX
VX	-0.5187E-06	0.1685E-05	0.1030E-10	0.7352E-13	0.2620E-11	-0.1434E-11	NY
VXPY	-0.2964E-11	0.1030E-10	0.4408E-05	-0.5423E-13	-0.6162E-12	-0.1798E-11	NXY
WXX	-0.1553E-11	0.1092E-12	-0.5423E-13	0.2886E-02	-0.1793E-02	-0.4165E-03	MX
WYY	-0.2719E-12	0.2659E-11	-0.6162E-12	-0.1793E-02	0.1421E-01	-0.4733E-02	MY
WXY	0.2880E-12	-0.1463E-11	-0.1798E-11	-0.4165E-03	-0.4733E-02	0.1723E-01	MXY

DISP.	DISPLACEMENT FORCE RELATIONS						FORCES
0.8129E-02	0.1685E-05	-0.5187E-06	-0.2964E-11	-0.1567E-11	-0.6338E-13	0.2138E-12	0.4745E 04
-0.2891E-02	-0.5187E-06	0.1685E-05	0.1030E-10	0.7352E-13	0.2620E-11	-0.1434E-11	-0.2546E 03
-0.1811E-07	-0.2964E-11	0.1030E-10	0.4408E-05	-0.5423E-13	-0.6162E-12	-0.1798E-11	-0.3226E-03
0.1443E 00	-0.1553E-11	0.1092E-12	-0.5423E-13	0.2886E-02	-0.1793E-02	-0.4165E-03	0.5000E 02
-0.8965E-01	-0.2719E-12	0.2659E-11	-0.6162E-12	-0.1793E-02	0.1421E-01	-0.4733E-02	-0.7451E-07
-0.2083E-01	0.2880E-12	-0.1463E-11	-0.1798E-11	-0.4165E-03	-0.4733E-02	0.1723E-01	0.1118E-07

FOR THIS CASE NBS(X,Y,XY-M) IS 5000. 0. 0.

FOR THIS CASE MBS(X,Y,XY-M) IS 50. 0. 0.

LAYER PROPERTIES, RUWS-PROPERTY, COLUMNS-LAYER

1	KV	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	KF	0.5000E 00									
3	KFB	0.5000E 00									
4	KM	0.5000E 00									
5	KMB	0.5000E 00									
6	RHDL	0.5165E-01									
7	TL	0.8000E-02									
8	DELTA	0.6586E-04									
9	ILDC	-0.0000E-19	0.	0.	0.	0.	0.	0.	0.	0.	0.
10	ZB	0.4000E-02	0.1200E-01	0.2000E-01	0.2800E-01	0.3600E-01	0.4400E-01	0.5200E-01	0.5200E-01	0.5200E-01	0.5200E-01
11	ZGC	-0.2800E-01	-0.2000E-01	-0.1200E-01	-0.4000E-02	0.4000E-02	0.1200E-01	0.2000E-01	0.2000E-01	0.2000E-01	0.2000E-01
12	THCS	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
13	THLC	0.	0.7854E 00	-0.7854E 00	0.1571E 01	0.1571E 01	-0.7854E 00	0.7854E 00	0.7854E 00	0.	0.
14	THLS	0.	0.7854E 00	-0.7854E 00	0.1571E 01	0.1571E 01	-0.7854E 00	0.7854E 00	0.7854E 00	0.	0.
15	SC11	0.2549E 08									
16	SC12	0.4118E 06									
17	SC13	0.4118E 06									
18	SC22	0.1160E 07									
19	SC23	0.4787E 06									
20	SC33	0.1160E 07									
21	SC44	0.3405E 06									
22	SC55	0.3405E 06									
23	SC66	0.6339E 06									
24	CTE11	-0.6138E-07									
25	CTE22	0.2334E-04									
26	CTE33	0.2334E-04									
27	HK11	0.2906E 03									
28	HK22	0.3715E 01									
29	HK33	0.3715E 01									
30	HCL	0.2043E 00									
31	EL11	0.2528E 08									
32	EL22	0.9597E 06									
33	EL33	0.9597E 06									
34	GL23	0.3405E 06									
35	GL13	0.6339E 06									
36	GL12	0.6339E 06									
37	NUL12	0.2514E 00									
38	NUL21	0.9541E-02									
39	NUL13	0.2514E 00									
40	NUL31	0.9541E-02									
41	NUL23	0.4094E 00									
42	NUL32	0.4094E 00									
43	SMFK22	0.1522E 01									
44	SMF22	0.1918E 01									
45	SMFS22	0.1358E 01	0.1371E 01	0.1372E 01	0.1388E 01	0.1389E 01					
46	SMF22	-0.0000E-19									
47	SMFS12	-0.3024E 01	0.3024E 01	0.3024E 01	0.3024E 01	0.3024E 01	0.3024E 01	0.3024E 01	0.3024E 01	0.3024E 01	0.3024E 01
48	SMFS23	0.1396E 01									
49	ILMFC	-0.0000E-19	0.7060E 02	0.7363E 02	0.7060E 02						
50	TEMPO	-0.3000E 03									
51	LSC11T	0.9676E 05									
52	LSC11C	0.5333E 05									
53	LSC11D	0.6578E 05									
54	LSC22T	0.3634E 04	0.3634E 04	0.3634E 04	0.3596E 04						
55	LSC22C	0.1767E 05	0.1750E 05	0.1749E 05	0.1729E 05	0.1727E 05					
56	LSC12	0.2547E 04									
57	LSC23	0.1866E 04									
58	LSCL23	-0.0000E-19									
59	LSCL13	-0.0000E-19									
60	LSCDF	-0.1000E-19	0.1052E-01	0.1352E-01	0.1052E-01						
61	KL12AB	0.1371E 01									
62	MDEIE	-0.1262E 01	-0.5395E 01	-0.8342E 01	-0.2019E 02	-0.2522E 02	-0.1613E 02	-0.2031E 02	-0.5998E 01	-0.5998E 01	-0.5998E 01
63	RELROT	-0.0000E-19	0.7082E 00	0.3240E 00	0.1925E 00	0.9916E 00	0.9633E 00	0.5456E 00	0.9364E 00	0.9364E 00	0.9364E 00
64	EPS11	0.4084E-02	0.2281E-02	0.2165E-02	-0.2532E-02	-0.3249E-02	0.3072E-02	0.2957E-02	-0.1217E-01	-0.1217E-01	-0.1217E-01
65	EPS22	-0.3804E-03	0.1864E-02	0.2416E-02	0.7551E-02	0.8706E-02	0.2822E-02	0.3374E-02	-0.5401E-02	-0.5401E-02	-0.5401E-02
66	EPS12	0.5831E-03	-0.6340E-02	0.8212E-02	-0.8321E-04	0.8341E-04	0.1383E-01	-0.1570E-01	-0.5832E-03	-0.5832E-03	-0.5832E-03
67	SIG11	0.9948E 05	0.5894E 05	0.5658E 05	-0.6236E 05	-0.7930E 05	0.8119E 05	0.7686			

THORNEL-50/EPUXY

NL,NPL,NPC,NPPE,NLC  
E 71 54 1420 1  
EF11,EF22,EF23,NUF12,NUF23,NUFL3,EF12,EF23,EF13,EM11,EM22,EM33,NUM12,NU423 NUM13,FM12,EM23,FM13  
0.5000E 08 0.1000E 07 0.1000E 07 0.2000E 03 0.2500E 03 0.2000E 00 0.1300E 07 0.7000E 06 0.1300E 07 0.5700E 06  
0.5700E 06 0.5700E 06 0.3600E 00 0.3600E 03 0.3600E 00 0.  
VCF  
0.4000E 01 0.2000E 01 0.4000E 01 0.2000E 01 0.  
0.  
0.  
0.  
VAF  
-0.5500E-06 0.5600E-05 0.5600E-05  
VAM  
0.4280E-04 0.4280E-04 0.4280E-04  
CHK  
0.5800E 03 0.5800E 02 0.5800E 02 0.1700E 00 0.1250E 01 0.1250E 01 0.1250E 01 0.2500E 00 0.  
0.  
BTA  
0.1000E 01 0.1000E 01 0.1000E 01 0.1050E 01  
PIE  
0.31416E 01  
TL INP  
F  
CSANB  
F  
BIDE  
F  
R INDV  
F  
THCS,RHOF,RHCM,DIAB  
0.  
KVL  
0.5900E-01 0.44300E-01 0.26000E-03  
KVL  
0.  
KPL  
0.  
0.5000E 00  
THLC  
0.  
TL  
0.8050E-02 0.8050E-02 0.8000E-02 0.8000E-02 0.8000E-02 0.8050E-02 0.8050E-02 0.8000E-02  
PTEMP  
-0.3000E 03  
BET  
0.8300E 00 0.1000E 01 0.2600E 00 0.2700E 00 0.1700E 00 0.1650E 02 0.1000E 01 0.1000E 01 0.4650E-01 0.1000E 01  
0.5000E 00 0.1330E 02 0.3190E 05 0.1000E 01 0.1000E 01 0.1000E 01 0.1000E 01  
LSC  
0.2300E 06 0.2100E 05 0.2000E-01 0.5000E-01 0.45000E-01 0.45000E-01  
NBS  
0.5000E 04 0.  
MBS  
0.5000E 02 0.  
DISV1  
0.  
0.  
0.  
0.  
0.  
0.

3-D COMPOSITE STRAIN STRESS TEMPERATURE RELATIONS - STRUCTURAL AXES

0.7604E-07	-0.1392E-08	-0.2866E-07	0.	0.	0.2400E-13	0.9901E-06
-0.1392E-08	0.7604E-07	-0.2866E-07	-0.	-0.	0.5238E-11	0.9901E-06
-0.2866E-07	-0.2866E-07	0.3844E-06	0.	0.	-0.2187E-11	0.3219E-04
0.	0.	-0.	0.2937E-05	0.	0.	0.
0.	0.	-0.	0.	0.2937E-05	0.	0.
0.2400E-13	0.5238E-11	-0.2187E-11	0.	0.	0.1578E-05	0.1228E-09

3-D COMPOSITE STRESS STRAIN RELATIONS - STRUCTURAL AXES

0.1333E 08	0.4118E 06	0.4452E 06	-0.	-0.	-0.9527E 00	
0.4118E 06	0.1333E 08	0.4452E 06	-0.	-0.	-0.4363E 02	
0.4452E 06	0.4452E 06	0.1160E 07	-0.	-0.	0.1225E 00	
-0.	-0.	-0.	0.3405E 06	-0.	-0.	
-0.	-0.	-0.	-0.	0.3405E 06	-0.	
-0.9527E 00	-0.4363E 02	0.1225E 00	-0.	-0.	0.6339E 06	

COMPOSITE PROPERTIES - VALID ONLY FOR CONSTANT TEMPERATURE THROUGH THICKNESS  
 LINES 1 TO 31 3-D COMPOSITE PROPERTIES ABOUT MATERIAL AXES  
 LINES 33 TO 54 2-D COMPOSITE PROPERTIES ABOUT STRUCTURAL AXES

1	RHOC	0.5165E-01
2	TC	C.6400E-01
3	CC11	C.1333E 08
4	CC12	0.4118E 06
5	CC13	0.4452E 06
6	CC22	0.1333E 08
7	CC23	C.4452E 06
8	CC33	0.1160E 07
9	CC44	0.3405E 06
10	CC55	0.3405E 06
11	CC66	0.5339E 06
12	CTE11	C.9901E-06
13	CTE22	C.9901E-06
14	CTE33	C.3219E-04
15	HK11	C.1472E 03
16	HK22	C.1472E 03
17	HK33	C.3715E 01
18	HHC	C.2043E 00
19	EC11	0.1315E 08
20	EC22	0.1315E 08
21	EC33	0.1131E 07
22	EC23	0.3405E 06
23	EC31	C.3405E 06
24	EC12	0.6339E 06
25	NUC12	0.1831E-01
26	NUC21	0.1831E-01
27	NUC13	0.3769E 00
28	NUC31	0.3241E-01
29	NUC23	0.3769E 00
30	NUC32	0.3241E-01
31	ZCGC	C.3200E-01
32	B2DEC	C.
33	CC11	0.1315E 08
34	CC12	0.2418E 06
35	CC13	- C.1003E 01
36	CC22	0.1315E 08
37	CC23	- C.4368E 02
38	CC33	C.6339E 06
39	EC11	0.1315E 08
40	EC22	0.1315E 08
41	EC12	0.6339E 06
42	NUC12	0.1838E-01
43	NUC21	0.1838E-01
44	CSN13	- C.3161E-06
45	CSN31	-0.1524E-07
46	CSN23	- C.6887E-04
47	CSN32	-0.3320E-05
48	CTE11	C.9901E-06
49	CTE22	C.9901E-06
50	CTE12	C.1228E-09
51	HK11	C.1472E 03
52	HK22	C.1472E 03
53	HK12	0.5594E-03
54	HHC	C.2043E 00

FORCES			FORCE DISPLACEMENT RELATIONS				DISPL	THERMAL FORCES	
NX	0.8419E 06	0.1548E 05	-0.5421E-01	0.3662E-03	0.2384E-05	0.1091E-10	UX	-0.2545E 03	
NY	0.1549E 05	0.8419E 06	-0.2795E 01	0.1907E-05	0.4387E-04	0.3492E-09	VX	-0.2546E 03	
NXY	-0.5421E-01	-0.2795E 01	0.4057E 05	0.1091E-10	0.4657E-09	0.5722E-05	VXPY	-0.6455E-03	
MX	C.3662E-03	0.1907E-05	0.1091E-10	0.3872E 03	0.5283E 01	-0.1370E-04	WXX	-0.7451E-03	
MY	0.2384E-05	0.4387E-04	0.4657E-09	0.5283E 01	0.1875E 03	-0.5963E-03	WYY	-0.7451E-07	
MXY	0.1091E-10	0.3492E-09	0.5722E-05	-0.1370E-04	-0.5963E-03	0.1385E 02	WXY	0.8527E-13	

#### REDUCED BENDING RIGIDITIES

0.3872E 03 0.52825E 01 -0.13698E-04 0.52825E 01 0.18748E 03 -0.59633E-03 -0.13698E-04 -0.59633E-03 0.13847E 02

REDUCED STIFFNESS MATRIX  
 0.84185E 06 0.15476E 05 -0.64211E-01 0.15476E 05 0.84185E 06 -0.27953E 01 -0.64211E-01 -0.27953E 01 0.40569E 05

DISP.	DISPLACEMENT FORCE RELATIONS					FORCES
UX	0.1198E-05	-0.2184E-07	0.3756E-12	-0.1124E-11	0.2167E-13	-0.7195E-18
VX	-0.2184E-07	C.1198E-05	0.8184E-10	0.1860E-13	-0.2783E-12	-0.7574E-16
VXPY	C.3756E-12	0.8184E-10	0.2465E-04	-0.2750E-18	-0.1128E-15	-0.1019E-10

WXX	-0.1124E-11	0.1714E-13	-0.5847E-18	0.2583E-02	-0.7279E-04	-0.5792E-09	MX
WYY	0.2469E-13	-0.2783E-12	-0.9746E-16	-0.7279E-04	0.5336E-02	0.2297E-06	MY
WXY	-0.4057E-18	-0.8573E-16	-0.1019E-10	-0.5792E-09	0.2297E-06	0.7222E-01	MMY

DISP.	DISPLACEMENT FORCE RELATIONS						FORCES
0.5644E-02	0.1188E-05	-0.2184E-07	0.3756E-12	-0.1124E-11	0.2167E-13	-0.7195E-18	0.4745E-14
-0.4062E-03	-0.2184E-07	0.1188E-05	0.8184E-10	0.1860E-13	-0.2783E-12	-0.7574E-16	-0.2546E-03
-0.3497E-07	0.3756E-12	0.8184E-10	0.2465E-04	-0.2750E-18	-0.1128E-15	-0.1019E-10	-0.6456E-03
0.1292E 00	-0.1124E-11	0.1714E-13	-0.5847E-18	0.2583E-02	-0.7279E-04	-0.5792E-09	0.5000E 02
-0.3640E-02	0.2469E-13	-0.2783E-12	-0.9746E-16	-0.7279E-04	0.5336E-02	0.2297E-06	-0.7451E-07
-0.2896E-07	-0.4057E-18	-0.8573E-16	-0.1019E-10	-0.5792E-09	0.2297E-06	0.7222E-01	0.8527E-13

FOR THIS CASE NBS(X,Y,XY-M) IS 5000. 0. 0.

FOR THIS CASE MBS(X,Y,XY-M) IS 50. 0. 0.

#### LAYER PROPERTIES, ROWS=PROPERTY, COLUMNS=LAYER

1	KV	0.	0.	0.	0.	0.	0.	0.
2	KF	0.5000E 00						
3	KFB	0.5000E 00						
4	KM	0.5000E 00						
5	KMB	0.5000E 00						
6	RHUL	0.5165E-01						
7	TL	0.8000E-02						
8	DELT A	0.6586E-04						
9	ILDC	-0.0000E-19	0.	0.	0.	0.	0.	0.
10	ZB	0.4000E-02	0.1200E-01	0.2000E-01	0.2800E-01	0.3600E-01	0.4400E-01	0.5200E-01
11	ZGC	-0.2800E-01	-0.2000E-01	-0.1200E-01	-0.4000E-02	0.4000E-02	0.1200E-01	0.2000E-01
12	THCS	0.	0.	0.	0.	0.	0.	0.
13	THLC	0.	0.1571E 01	0.	0.1571E 01	0.	0.1571E 01	0.
14	THLS	0.	0.1571E 01	0.	0.1571E 01	0.	0.1571E 01	0.
15	SC11	0.2549E 08						
16	SC12	0.4118E 05	0.4118E 06					
17	SC13	0.4118E 05	0.4118E 06					
18	SC22	0.1160E 07						
19	SC23	0.4787E 06						
20	SC33	0.1160E 07						
21	SC44	0.3405E 06						
22	SC55	0.3405E 06						
23	SC66	0.6339E 06						
24	CTE11	-0.6138E-07						
25	CTE22	0.2334E-04						
26	CTE33	0.2334E-04						
27	HK11	0.29C6E 03	0.2990E 03	0.2990E 03	0.2900E 03	0.2900E 03	0.2900E 03	0.2900E 03
28	HK22	0.3715E 01						
29	HK33	0.3715E 01						
30	HCL	0.2043E 00						
31	EL11	0.2528E 08						
32	EL22	0.9597E 06						
33	EL33	0.9597E 06						
34	GL23	0.3405E 06						
35	GL13	0.6339E 06						
36	GL12	0.6339E 06						
37	NUL12	0.2514E 00						
38	NUL21	0.9541E-02						
39	NUL13	0.2514E 00						
40	NUL31	0.9541E-02						
41	NUL23	0.4094E 00						
42	NUL32	0.4094E 00						
43	SMFK22	0.1522E 01						
44	SMFD22	0.1918E 01						
45	SMFS22	0.1369E 01	0.1382E 01	0.1357E 01	0.1382E 01	0.1382E 01	0.1337E 01	0.1382E 01
46	SMFC22	-0.0000E-19						
47	SMFS12	0.3024E 01						
48	SMFS23	0.1396E 01						
49	ILMFC	-0.1000E-19	0.7060E 02	0.7050E 02	0.7060E 02	0.7060E 02	0.7060E 02	0.7060E 02
50	TEMPO	-0.3000E 03						
51	LSC11T	0.9676E 05	0.9675E 05	0.9676E 05				
52	LSC11C	0.5333E 05						
53	LSC11D	0.6578E 05						
54	LSC22T	0.3644E 04	0.3610E 04	0.3679E 04	0.3610E 04	0.3631E 04	0.3731E 04	0.3610E 04
55	LSC22C	0.1752E 05	0.1736E 05	0.1769E 05	0.1736E 05	0.1736E 05	0.1794E 05	0.1736E 05
56	LSC12	0.2547E 04						
57	LSC23	0.1866E 04						
58	LSCC23	-0.0000E-19						
59	LSCC13	-0.0000E-19						
60	LSCDF	-0.0000E-19	0.1052E-01	0.1052E-01	0.1052E-01	0.1052E-01	0.1052E-01	0.1052E-01

61	KL12AB	0.1371E 01	0.1371E 01							
62	MDEIE	-0.1514E 01	-0.6581E 01	-0.1208E 01	-0.1002E 02	-0.1185E 02	-0.1650E 01	-0.1638E 02	-0.2525E 01	
63	RELROT	-0.0000E-19	0.1000E 01	0.1000E 01						
64	EPS11	0.2027E-02	-0.3334E-03	0.4094E-02	-0.3917E-03	-0.4208E-03	0.7194E-02	-0.4790E-03	0.9261E-02	
65	EPS22	-0.3043E-03	0.3061E-02	-0.3625E-03	0.5128E-02	0.6161E-02	-0.4499E-03	0.8228E-02	-0.5082E-03	
66	EPS12	-0.3416E-07	0.5927E-07	-0.3462E-07	0.7531E-07	0.8333E-07	-0.3532E-07	0.9936E-07	-0.3578E-07	
67	SIG11	0.5131E 05	-0.7299E 04	0.1057E 06	-0.8789E 04	-0.8199E 04	0.1851E 06	-0.1102E 05	0.2379E 06	
68	SIG22	0.6929E 04	0.9595E 04	0.7372E 04	0.1157E 05	0.1256E 05	0.8038E 04	0.1453E 05	0.8482E 04	
69	SIG12	-0.2165E-01	0.3757E-01	-0.2195E-01	0.4774E-01	0.5282E-01	-0.2239E-01	0.6298E-01	-0.2268E-01	
70	DELFI	-0.0000E-19	-0.3564E-07	-0.1009E-07	-0.4186E-07	0.4249E-08	-0.8689E-07	-0.5031E-07	-0.1535F-36	
71	HFC	-0.1267E 01	-0.2659E 01	-0.2548E 01	-0.3783E 01	-0.4372E 01	-0.6462E 01	-0.5704E 01	-0.1041E 02	

### Bidirectional Composite Residual Stresses Only

THORNEL-50/EPOXY

```

NL,NPL,NPC,NFPE,NLC
 8   71    54 1420   1

EF11,EF22,EF33,NUF12,NUF23,NUF13,EF12,EF23,EF13,EM11,EM22,EM33,NUM12,NUM23 NUM13,EM12,EM23,EM13
 0.50000E 08 0.10000E 07 0.10000E 07 0.20000E 03 0.25000E 03 0.20000E 00 0.13000E 07 0.70000E 06 0.13000E 07 0.57000E 05
 0.57000E 06 0.57000E 06 0.36000E 00 0.36000E 00 0.36000E 00 0.36000E 00 0. 0.
VCF
 0.40000E 01 0.20000E 01 0.40000E 01 0.20000E 01 0. 0. 0. 0. 0.23560E 01 0. 0.
 0. 0. 0. 0. 0.10000E 01 0.10000E 01 0.10000E 01 0. 0.
VAF
-0.55000E-06 0.56000E-05 0.56000E-05
VAM
 0.42800E-04 0.42800E-04 0.42800E-04
CHK
 0.58000E 03 0.58000E 02 0.58000E 02 0.17000E 00 0.12500E 01 0.12500E 01 0.12500E C1 0.25000E 00 0. 0.
 0. 0.22500E 00
BTA
 0.10000E 01 0.10000E 01 0.10500E 01 0.10500E 01
PIE
 0.31416E 01

TL INP
 F

CSANB
 F

BIDE
 F

RINDV
 F

THCS,RHOF,RHCM,DIAF
 0. 0.59000E-01 0.44300E-01 0.26000E-03
KVL
 0. 0. 0. 0. 0. 0. 0. 0.
KFL
 0.50000E 00 0.50000E 00
THLC
 0. 0.90000E C2 0. 0.90000E 02 0.90000E 02 0. 0.90000E C2 0.
TL
 0.80500E-02 J.80500E-02 0.80000E-02 0.80000E-02 0.80000E-02 0.80500E-02 0.80500E-02 0.80000E-02
PTMP
-0.30000E 03 -0.30000E 03
BET
 0.83000E 00 0.10000E 01 0.26000E 00 0.27000E 00 0.17000E 00 0.16500E 02 0.10000E 01 0.10000E 01 0.46500E-01 0.10000E 01
 0.50000E 00 J.13300E 02 0.31900E 05 0.10000E 01 0.10000E 01 0.10000E 01 0.10000E 01
LSC
 0.23000E 06 0.21000E 05 0.20000E-01 0.50000E-01 0.45000E-01 0.45000E-01
NBS
 0. 0. 0.
MBS
 0. 0. 0.
DISV1
 0. 0. 0. 0. 0. 0.

```

3-D COMPOSITE STRAIN STRESS TEMPERATURE RELATIONS - STRUCTURAL AXES

0.7604E-07	-0.1392E-08	-0.2866E-07	0.	0.	0.2400E-13	0.9901E-06
-0.1392E-08	0.7604E-07	-0.2866E-07	-0.	-0.	0.5238E-11	0.9901E-06
-0.2866E-07	-0.2866E-07	0.8844E-06	0.	0.	-0.2187E-11	0.3219E-04
0.	0.	-0.	0.2937E-05	0.	0.	0.
0.	0.	-0.	0.	0.2937E-05	0.	0.
1.2400E-13	0.5238E-11	-0.2187E-11	0.	0.	0.1578E-05	0.1228E-09

3-D COMPOSITE STRESS STRAIN RELATIONS - STRUCTURAL AXES

0.1333E 08	0.4118E 06	0.4452E 06	-0.	-0.	-0.9527E 00
0.4118E 06	0.1333E 08	0.4452E 06	-0.	-0.	-0.4363E 02
0.4452E 06	0.4452E 06	0.1160E 07	-0.	-0.	0.1225E 00
-0.	-0.	-0.	0.3405E 06	-0.	-0.
-0.	-0.	-0.	-0.	0.3405E 06	-0.
-0.9527E 00	-0.4363E 02	0.1225E 00	-0.	-0.	0.6339E 06

COMPOSITE PROPERTIES - VALID ONLY FOR CONSTANT TEMPERATURE THROUGH THICKNESS

LINES 1 TO 31 3-D COMPOSITE PROPERTIES ABOUT MATERIAL AXES

LINES 33 TO 54 2-D COMPOSITE PROPERTIES ABOUT STRUCTURAL AXES

1	RHOC	0.5165E-01
2	TC	0.6400E-01
3	CC11	0.1333E 03
4	CC12	0.4118E 06
5	CC13	0.4452E 06
6	CC22	0.1333E 08
7	CC23	0.4452E 06
8	CC33	0.1160E 07
9	CC44	0.3405E 06
10	CC55	0.3405E 06
11	CC66	0.6339E 06
12	CTE11	0.9901E-06
13	CTE22	0.9901E-06
14	CTE33	0.3219E-04
15	HK11	0.1472E 03
16	HK22	0.1472E 03
17	HK33	0.3715E 01
18	HHC	0.2043E 03
19	EC11	0.1315E 08
20	EC22	0.1315E 08
21	EC33	0.1131E 07
22	EC23	0.3405E 06
23	EC31	0.3405E 06
24	EC12	0.6339E 06
25	NUC12	0.1831E-01
26	NUC21	0.1831E-01
27	NUC13	0.3769E 00
28	NUC31	0.3241E-01
29	NUC23	0.3769E 00
30	NUC32	0.3241E-01
31	ZLGC	0.3200E-01
32	B2DEC	0.
33	CC11	0.1315E 03
34	CC12	0.2418E 06
35	CC13	-0.1003E 01
36	CC22	0.1315E 08
37	CC23	-0.4368E 02
38	CC33	0.5339E 06
39	EC11	0.1315E 08
40	EC22	0.1315E 08
41	EC12	0.6339E 06
42	NUC12	0.1838E-01
43	NUC21	0.1838E-01
44	CSN13	-0.3161E-06
45	CSN31	-0.1524E-07
46	CSN23	-0.5397E-04
47	CSN32	-0.3320E-05
48	CTE11	0.9901E-05
49	CTE22	0.9901E-06
50	CTE12	0.1228E-09
51	HK11	0.1472E 03
52	HK22	0.1472E 03
53	HK12	0.5594E-03
54	HHC	0.2043E 00

FORCES	FORCE DISPLACEMENT RELATIONS						DISPL	THERMAL FORCES
NX	0.8419E 06	0.1548E 05	-0.6421E-01	0.3662E-03	0.2384E-05	0.1091E-10	UX	-0.2546E 03
NY	0.1548E 05	0.8419E 06	-0.2795E 01	0.1907E-05	0.4387E-04	0.3492E-09	VX	-0.2546E 03
NXY	-0.6421E-01	-0.2795E 01	0.4057E 05	0.1091E-10	0.4657E-09	0.5722E-05	VXPY	-0.6456E-03
MX	0.3662E-03	0.1907E-05	0.1091E-10	0.3872E 03	0.5283E 01	-0.1370E-04	WXX	-0.7451E-08
MY	0.2384E-05	0.4387E-04	0.4657E-09	0.5283E 01	0.1875E 03	-0.5963E-03	WYY	-0.7451E-07
MXY	0.1091E-10	0.3492E-09	0.5722E-05	-0.1370E-04	-0.5963E-03	0.1385E 02	WXY	0.8527E-13

#### REDUCED BENDING REGIDITIES

0.38723E C3 0.52825E 01 -0.13698E-04 0.52825E 01 0.18748E 03 -0.59633E-03 -0.13698E-04 -0.59633E-03 0.13847E 02

#### REDUCED STIFFNESS MATRIX

0.84185E 06 0.15476E 05 -0.64211E-01 0.15476E 05 0.84185E 06 -0.27953E 01 -0.64211E-01 -0.27953E 01 0.40568E 05

DISP.	DISPLACEMENT FORCE RELATIONS						FORCES
UX	0.1188E-05	-0.2184E-07	0.3756E-12	-0.1124E-11	0.2167E-13	-0.7195E-18	NX
VX	-0.2184E-07	0.1188E-05	0.8184E-10	0.1860E-13	-0.2783E-12	-0.7574E-16	NY
VXPY	0.3756E-12	0.8184E-10	0.2465E-04	-0.2750E-18	-0.1128E-15	-0.1019E-10	NXY
WXX	-0.1124E-11	0.1714E-13	-0.5847E-18	0.2583E-02	-0.7279E-04	-0.5792E-09	MX
WYY	0.2469E-13	-0.2783E-12	-0.9746E-16	-0.7279E-04	0.5336E-02	0.2297E-06	MY
WXY	-0.4057E-18	-0.8573E-16	-0.1019E-10	-0.5792E-09	0.2297E-06	0.7222E-01	MXY

DISP.	DISPLACEMENT FORCE RELATIONS						FORCES
-0.2970E-03	0.1188E-05	-0.2184E-07	0.3756E-12	-0.1124E-11	0.2167E-13	-0.7195E-18	-0.2546E 03
-0.2970E-03	-0.2184E-07	0.1188E-05	0.8184E-10	0.1860E-13	-0.2783E-12	-0.7574E-16	-0.2546E 03
-0.3685E-07	0.3756E-12	0.8184E-10	0.2465E-04	-0.2750E-18	-0.1128E-15	-0.1019E-10	-0.6456E-03
0.2680E-09	-0.1124E-11	0.1714E-13	-0.5847E-18	0.2583E-02	-0.7279E-04	-0.5792E-09	-0.7451E-08
-0.3324E-09	0.2469E-13	-0.2783E-12	-0.9746E-16	-0.7279E-04	0.5336E-02	0.2297E-06	-0.7451E-07
0.1756E-13	-0.4057E-18	-0.8573E-16	-0.1019E-10	-0.5792E-09	0.2297E-06	0.7222E-01	0.8527E-13

FOR THIS CASE NBS(X,Y,XY-M) IS 0. 0. 0.

FOR THIS CASE MBS(X,Y,XY-M) IS 0. 0. 0.

#### LAYER PROPERTIES, ROWS-PROPERTY, COLUMNS-LAYER

1 KV	0.	0.	0.	0.	0.	0.	0.	0.
2 KF	0.5000E 00	0.5000E 00	0.5000E 00	0.5000E 00	0.5000E 00	0.5000E 00	0.5000E 00	0.5000E 00
3 KFB	0.5000E 00	0.5000E 00	0.5000E 00	0.5000E 00	0.5000E 00	0.5000E 00	0.5000E 00	0.5000E 00
4 KM	0.5000E 00	0.5000E 00	0.5000E 00	0.5000E 00	0.5000E 00	0.5000E 00	0.5000E 00	0.5000E 00
5 KMB	0.5000E 00	0.5000E 00	0.5000E 00	0.5000E 00	0.5000E 00	0.5000E 00	0.5000E 00	0.5000E 00
6 RHOL	0.5165E-01	0.5165E-01	0.5165E-01	0.5165E-01	0.5165E-01	0.5165E-01	0.5165E-01	0.5165E-01
7 TL	0.8000E-02	0.8000E-02	0.8000E-02	0.8000E-02	0.8000E-02	0.8000E-02	0.8000E-02	0.8000E-02
8 DELTA	0.6586E-04	0.6586E-04	0.6586E-04	0.6586E-04	0.6586E-04	0.6586E-04	0.6586E-04	0.6586E-04
9 ILDC	-0.0600E-19	0.	0.	0.	0.	0.	0.	0.
10 ZB	0.4000E-02	0.1200E-01	0.2000E-01	0.2800E-01	0.3600E-01	0.4400E-01	0.5200E-01	0.6000E-01
11 ZG	-0.2800E-01	-0.2000E-01	-0.1200E-01	-0.4000E-02	0.4000E-02	0.1200E-01	0.2000E-01	0.2800E-01
12 THCS	0.	0.	0.	0.	0.	0.	0.	0.
13 THLC	0.	0.1571E 01	0.	0.1571E 01	0.1571E 01	0.	0.1571E 01	0.
14 THLS	0.	0.1571E 01	0.	0.1571E 01	0.1571E 01	0.	0.1571E 01	0.
15 SC11	0.2549E 08	0.2549E 08	0.2549E 08	0.2549E 08	0.2549E 08	0.2549E 08	0.2549E 08	0.2549E 08
16 SC12	0.4118E 06	0.4118E 06	0.4118E 06	0.4118E 06	0.4118E 06	0.4118E 06	0.4118E 06	0.4118E 06
17 SC13	0.4118E 06	0.4118E 06	0.4118E 06	0.4118E 06	0.4118E 06	0.4118E 06	0.4118E 06	0.4118E 06
18 SC22	0.1160E 07	0.1160E 07	0.1160E 07	0.1160E 07	0.1160E 07	0.1160E 07	0.1160E 07	0.1160E 07
19 SC23	0.4787E 06	0.4787E 06	0.4787E 06	0.4787E 06	0.4787E 06	0.4787E 06	0.4787E 06	0.4787E 06
20 SC33	0.1160E 07	0.1160E 07	0.1160E 07	0.1160E 07	0.1160E 07	0.1160E 07	0.1160E 07	0.1160E 07
21 SC44	0.3405E 06	0.3405E 06	0.3405E 06	0.3405E 06	0.3405E 06	0.3405E 06	0.3405E 06	0.3405E 06

22	SC55	0.3405E 06	0.3405E 05	0.3405E 06	0.3405E 06	0.3405E 06	0.3405E 06	0.3405E 05	0.3405E 06
23	SC66	0.6339E 05	0.6339E 06	0.6339E 05	0.6339E 06				
24	CTE11	-0.6138E-07							
25	CTE22	0.2334E-04							
26	CTE33	0.2334E-04							
27	HK11	0.2906E 03							
28	HK22	0.3715E 01							
29	HK33	0.3715E 01							
30	FCL	0.2043E 00							
31	EL11	0.2528E 03							
32	EL22	0.9597E 06							
33	EL33	0.9597E 06							
34	GL23	0.3405E 06	0.3405E 05	0.3405E 06	0.3405E 06	0.3405E 06	0.3405E 06	0.3405E 05	0.3405E 06
35	GL13	0.6339E 06							
36	GL12	0.6339E 05	0.6339E 06						
37	NUL12	0.2514E 03	0.2514E 00						
38	NUL21	0.9541E-02							
39	NUL13	0.2514E 03	0.2514E 00						
40	NUL31	0.9541E-02							
41	NUL23	0.4094E 00							
42	NUL32	0.4094E 00							
43	SMFK22	0.1522E 01							
44	SMFD22	0.1919E 01							
45	SMFS22	0.1383E 01							
46	SMFL22	-0.0000E-19							
47	SMFS12	0.3024E 01							
48	SMFS23	0.1396E 01							
49	ILMFC	-0.0000E-19	0.7060E 02						
50	TEMPO	-0.3000E 03							
51	LSC11T	0.9675E 05	0.9676E 05						
52	LSC11C	0.5333E 05							
53	LSC11U	0.6573E 05	0.6578E 05						
54	LSC22T	0.3609E 04							
55	LSC22C	0.1735E 05							
56	LSC12	0.2547E 04							
57	LSC23	0.1865E 04	0.1866E 04						
58	LSCL23	-0.3000E-19							
59	LSCL13	-0.0000E-19							
60	LSC0F	-0.0000E-19	0.1052E-01						
61	KL12AB	0.1371E 01							
62	MDEIE	-0.2422E 01							
63	REL40T	-0.3000E-19	0.1000E 01						
64	EPS11	-0.2970E-03							
65	EPS22	-0.2970E-03							
66	EPS12	-0.3689E-07	0.3685E-07	-0.3685E-07	0.3685E-07	-0.3685E-07	0.3685E-07	0.3685E-07	-0.3685E-07
67	SIG11	-0.6374E 04							
68	SIG22	0.6374E 04							
69	SIG12	-0.2333E-01	0.2336E-01	-0.2336E-01	0.2336E-01	-0.2336E-01	0.2336E-01	0.2336E-01	-0.2336E-01
70	DELFI	-0.0000E-19	-0.1278E-08						
71	FPC	-0.1117E 01							

### Bidirectional Composite with Bending-Stretching Coupling; Residual Stresses Only

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THCRNL-50/EPOXY

NL,NPL,NPC,NPPE,NLC
  8    71   54 1420   1

EF11,EF22,EF23,NUF12,NUF23,NUF13,EF12,EF23,EF13,EM11,EM22,EM33,NUM12,NUM23 NUM13,EM12,EM23,EM13
  0.50000E 08 0.10000E 07 0.10000E 07 0.20000E 03 0.25000E 03 0.20000E 00 0.13000E 07 0.70000E 06 0.13000E 07 0.57000E 06
  0.57000E 06 0.57000E 06 0.36000E 00 0.36000E 00 0.36000E 00 0.36000E 00 0.36000E 00 0.36000E 00 0.36000E 00
VCF
  0.40000E 01 0.20000E 01 0.40000E 01 0.20000E 01 0. 0. 0. 0. 0.23560E 01 0. 0. 0.
  0. 0. 0. 0.10000E 01 0.10000E 01 0.10000E 01 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
VAF
-0.55000E-06 0.56000E-05 0.56000E-05
VAM
  0.42800E-04 0.42800E-04 0.42800E-04
CHK
  0.58000E 03 0.58000E 02 0.58000E 02 0.17000E 00 0.12500E 01 0.12500E 01 0.12500E 01 0.25000E 00 0. 0.
  0. 0.22500E 00
BTA
  0.10000E 01 0.10000E 01 0.10500E 01 0.10500E 01
PIE
  0.31416E 01

TL INP
  F

CSANS
  F

BICE
  F

RINDV
  F

```

THCS,RHOF,RHCM,DIAF  
 0. 0.59000E-01 0.44300E-01 0.26000E-03  
 KVL  
 0. 0. 0. 0. 0. 0. 0. 0.  
 KFL  
 0.5000E 00 0.50000E 00  
 THLC  
 0. 0. 0. 0. 0.90000E 02 0.90000E 02 0.90000E 02 0.90000E 02  
 TL  
 0.80500E-02 0.80500E-02 0.80000E-02 0.80000E-02 0.80000E-02 0.80500E-02 0.80500E-02 0.80000E-02  
 PTEMP  
 -0.30000E 03  
 BET  
 0.83000E 00 0.10000E 01 0.26000E 00 0.27000E 00 0.17000E 00 0.16500E 02 0.10000E 01 0.10000E 01 0.46500E-01 0.10000E 01  
 0.50000E 00 0.13300E 02 0.31900E 05 0.10000E 01 0.10000E 01 0.10000E 01  
 LSC  
 0.23000E 06 0.21000E 05 0.20000E-01 0.50000E-01 0.45000E-01 0.45000E-01  
 NBS  
 0. 0. 0.  
 MBS  
 0. 0. 0.  
 DISV1  
 0. 0. 0. 0. 0. 0.

#### 3-D COMPOSITE STRAIN STRESS TEMPERATURE RELATIONS - STRUCTURAL AXES

0.7604E-07	-0.1392E-08	-0.2866E-07	0.	0.	0.2400E-13	0.9901E-06
-0.1392E-08	0.7604E-07	-0.2866E-07	-0.	-0.	0.5238E-11	0.9901E-06
-0.2866E-07	-0.2866E-07	0.8844E-06	0.	0.	-0.2187E-11	0.3219E-04
0.	0.	-0.	0.2937E-05	0.	0.	0.
0.	0.	-0.	0.	0.2937E-05	0.	0.
0.2400E-13	0.5238E-11	-0.2187E-11	0.	0.	0.1578E-05	0.1228E-09

#### 3-D COMPOSITE STRESS STRAIN RELATIONS - STRUCTURAL AXES

0.1333E 08	0.4118E 06	0.4452E 06	-0.	-0.	-0.9527E 00
0.4118E 06	0.1333E 08	0.4452E 06	-0.	-0.	-0.4363E 02
0.4452E 06	0.4452E 06	0.1160E 07	-0.	-0.	0.1225E 00
-0.	-0.	-0.	0.3405E 06	-0.	-0.
-0.	-0.	-0.	-0.	0.3405E 06	-0.
-0.9527E 00	-0.4363E 02	0.1225E 00	-0.	-0.	0.6339E 06

COMPOSITE PROPERTIES - VALID ONLY FOR CONSTANT TEMPERATURE THROUGH THICKNESS  
 LINES 1 TO 31 3-D COMPOSITE PROPERTIES ABOUT MATERIAL AXES  
 LINES 33 TO 54 2-D COMPOSITE PROPERTIES ABOUT STRUCTURAL AXES

1	RHOC	0.5165E-01
2	TC	0.6400E-01
3	CC11	0.1333E 08
4	CC12	0.4118E 06
5	CC13	0.4452E 06
6	CC22	0.1333E 08
7	CC23	0.4452E 06
8	CC33	0.1160E 07
9	CC44	0.3405E 06
10	CC55	0.3405E 06
11	CC66	0.6339E 06
12	CTE11	0.9901E-06
13	CTE22	0.9901E-06
14	CTE33	0.3219E-04
15	HK11	0.1472E 03
16	HK22	0.1472E 03
17	HK33	0.3715E 01
18	HHC	0.2043E 00
19	EC11	0.1315E 08
20	EC22	0.1315E 08
21	EC33	0.1131E 07
22	EC23	0.3405E 06
23	EC31	0.3405E 06
24	EC12	0.6339E 06
25	NUC12	0.1831E-01
26	NUC21	0.1831E-01
27	NUC13	0.3769E 00
28	NUC31	0.3241E-01
29	NUC23	0.3769E 00
30	NUC32	0.3241E-01
31	ZCGC	0.3200E-01
32	B2DEC	0.

33	CC11	0.1315E 08
34	CC12	0.2418E 06
35	CC13	-0.1003E 01
36	CC22	0.1315E 08
37	CC23	-0.4368E 02
38	CC33	0.5339E 06
39	EC11	0.1315E 08
40	EC22	0.1315E 08
41	EC12	0.6339E 06
42	NUC12	0.1838E-01
43	NUC21	0.1938E-01
44	CSN13	-0.3161E-05
45	CSN31	-0.1524E-07
46	CSN23	-0.6887E-04
47	CSN32	-0.3320E-05
48	CTE11	0.9930E-05
49	CTE22	0.3901E-06
50	CTE12	0.1228E-09
51	HK11	0.1472E 03
52	HK22	0.1472E 03
53	HK12	0.5594E-03
54	HHC	0.2343E 00

FORCES	FORCE DISPLACEMENT RELATIONS						DISPL	THERMAL FORCES
NX	0.8419E 06	0.1548E 05	-0.6421E-01	-0.1248E 05	0.3338E-05	-0.1027E-02	UX	-0.2545E 03
NY	0.1548E 05	0.8419E 06	-0.2795E 01	-0.9537E-06	0.1248E 05	-0.4472E-01	VX	-0.2545E 03
NXY	-0.6421E-01	-0.2795E 01	0.4057E 05	-0.1027E-02	-0.4472E-01	0.5722E-05	VXPY	-0.6455E-03
MX	-0.1248E 05	-0.9537E-06	-0.1027E-02	0.2874E 03	0.5283E 01	-0.2192E-04	WXX	-0.2818E 01
MY	0.3338E-05	0.1248E 05	-0.4472E-01	0.5283E 01	0.2874E 03	-0.9541E-03	WYY	0.2818E 01
MXY	-0.1027E-02	-0.4472E-01	0.5722E-05	-0.2192E-04	-0.9541E-03	0.1385E 02	WXY	-0.1033E-04

#### REDUCED RENDING RIGIDITIES

0.10215E 03 0.16776E 01 -0.24951E-04 0.18778E 01 0.10215E 03 -0.29092E-03 -0.24961E-04 -0.29092E-03 0.13847E 02

REDUCED STIFFNESS MATRIX  
 0.29526E 05 0.55014E 04 -0.73129E-01 0.55014E 04 0.29926E 06 -0.85231E 00 -0.73129E-01 -0.85231E 00 0.40568E 05

DISP.	DISPLACEMENT FORCE RELATIONS						FORCES
UX	0.3843E-05	-0.6145E-07	0.4735E-11	0.1452E-03	-0.1137E-12	0.2794E-09	NX
VX	-0.6145E-07	0.3843E-05	0.7012E-10	-0.5592E-13	-0.1452E-03	0.7851E-09	NY
VXPY	0.4735E-11	0.7012E-10	0.2465E-04	0.2794E-09	0.7851E-09	-0.9905E-11	NXY
WXX	0.1452E-03	-0.5634E-13	0.2794E-09	0.9793E-02	-0.1800E-03	0.1387E-07	MX
WYY	0.6770E-13	-0.1452E-03	0.7851E-09	-0.1800E-03	0.9793E-02	0.2054E-06	MY
WXY	0.2794E-09	0.7851E-09	-0.9905E-11	0.1387E-07	0.2054E-06	0.7222E-01	MXY

DISP.	DISPLACEMENT FORCE RELATIONS						FORCES
-0.1245E-02	0.3843E-05	-0.6145E-07	0.4735E-11	0.1452E-03	-0.1137E-12	0.2794E-09	-0.2546E 03
-0.1245E-02	-0.6145E-07	0.3843E-05	0.7012E-10	-0.5592E-13	-0.1452E-03	0.7851E-09	-0.2546E 03
-0.3355E-07	0.4735E-11	0.7012E-10	0.2465E-04	0.2794E-09	0.7851E-09	-0.9905E-11	-0.6456E-03
-0.6509E-01	0.1452E-03	-0.5634E-13	0.2794E-09	0.9793E-02	-0.1800E-03	0.1387E-07	-0.2818E 01
0.6509E-01	0.6770E-13	-0.1452E-03	0.7851E-09	-0.1800E-03	0.9793E-02	0.2054E-06	0.2818E 01
-0.4771E-06	0.2794E-09	0.7851E-09	-0.9905E-11	0.1387E-07	0.2054E-06	0.7222E-01	-0.1033E-04

FOR THIS CASE NBS(X,Y,XY-M) IS 0. 0. 0.

FOR THIS CASE MBS(X,Y,XY-M) IS 0. 0. 0.

LAYER PROPERTIES, ROWS-PROPERTY, COLUMNS-LAYER

1	KV	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	KF	0.5000E 00								
3	KFB	0.5000E 00								
4	KM	0.5000E 00								
5	KMB	0.5000E 00								
6	RHOL	0.5165E-01								
7	TL	0.8000E-02								
8	DELT A	0.6586E-04								
9	ILDC	-0.0000E-19	0.	0.	0.	0.	0.	0.	0.	0.
10	ZB	0.4000E-02	0.1200E-01	0.2000E-01	0.2800E-01	0.3600E-01	0.4400E-01	0.5200E-01	0.6000E-01	0.6800E-01
11	ZGC	-0.2800E-01	-0.2000E-01	-0.1200E-01	-0.4000E-02	0.4000E-02	0.1200E-01	0.2000E-01	0.2800E-01	0.3600E-01
12	THCS	0.	0.	0.	0.	0.	0.	0.	0.	0.
13	THLC	0.	0.	0.	0.	0.	0.	0.	0.	0.
14	THLS	0.	0.	0.	0.	0.	0.	0.	0.	0.
15	SC11	0.2549E 08								
16	SC12	0.4118E 06								
17	SC13	0.4118E 06								
18	SC22	0.1160E 07								
19	SC23	0.4787E 06								
20	SC33	0.1160E 07								
21	SC44	0.3405E 06								
22	SC55	0.3405E 06								
23	SC66	0.6339E 06								
24	CTE11	-0.6138E-07								
25	CTE22	0.2334E-04								
26	CTE33	0.2334E-04								
27	HK11	0.2906E 03								
28	HK22	0.3715E 01								
29	HK33	0.3715E 01								
30	HCL	0.2043E 00								
31	EL11	0.2529E 08	0.2528E 08							
32	EL22	0.9597E 06								
33	EL33	0.9597E 06								
34	GL23	0.3405E 06								
35	GL13	0.6339E 06								
36	GL12	0.6339E 06								
37	NUL12	0.2514E 03								
38	NUL21	0.9541E-02								
39	NUL13	0.2514E 00								
40	NUL31	0.9541E-02								
41	NUL23	0.4094E 00								
42	NUL32	0.4094E 00								
43	SMFK22	0.1522E 01								
44	SMFD22	0.1918E 01								
45	SMFS22	0.1386E 01	0.1384E 01	0.1382E 01	0.1379E 01					
46	SMFC22	-0.0000E-19								
47	SMFS12	0.3024E 01								
48	SMFS23	0.1395E 01	0.1396E 01							
49	ILMFC	-0.0000E-19	0.7060E 02							
50	TEMPO	-0.3000E 03								
51	LSC11T	0.9676E 05								
52	LSC11C	0.5333E 05								
53	LSC11D	0.6578E 05								
54	LSC22T	0.3601E 04	0.3607E 04	0.3612E 04	0.3619E 04					
55	LSC22C	0.1731E 05	0.1734E 05	0.1737E 05	0.1740E 05					
56	LSC12	0.2547E 04								
57	LSC23	0.1866E 04								
58	LSCC23	-0.0000E-19								
59	LSCC13	-0.0000E-19								
60	LSCDF	-0.0000E-19	0.1052E 01							
61	KL12AB	0.1371E 01								
62	MDEIE	-0.7038E 01	-0.5461E 01	-0.4100E 01	-0.3201E 01	-0.3201E 01	-0.4100E 01	-0.5461E 01	-0.7038E 01	-0.7038E 01
63	RELROT	-0.3000E-19	0.1000E 01							
64	EPS11	-0.1172E-02	-0.6510E-03	-0.1302E-03	0.3905E-03	0.3905E-03	-0.1302E-03	-0.6510E-03	-0.1172E-02	-0.1172E-02
65	EPS22	0.2473E-02	0.1953E-02	0.1432E-02	0.9112E-03	0.9112E-03	0.1432E-02	0.1953E-02	0.2473E-02	0.2473E-02
66	EPS12	-0.5351E-07	-0.4969E-07	-0.4588E-07	-0.4206E-07	0.4206E-07	0.4588E-07	0.4969E-07	0.5351E-07	0.5351E-07
67	SIG11	-0.2787E 05	-0.1480E 05	-0.1729E 04	0.1134E 05	0.1134E 05	-0.1729E 04	-0.1480E 05	-0.2787E 05	-0.2787E 05
68	SIG22	0.3827E 04	0.8452E 04	0.8077E 04	0.7723E 04	0.7723E 04	0.8077E 04	0.8452E 04	0.8827E 04	0.8827E 04
69	SIG12	-0.3392E-01	-0.3150E-01	-0.2908E-01	-0.2666E-01	0.2666E-01	0.2908E-01	0.3150E-01	0.3392E-01	0.3392E-01
70	DELFI	-0.0000E-19	-0.4752E-08	-0.4093E-09	0.1839E-08	0.3581E-08	-0.3070E-09	-0.2927E-08	-0.5798E-08	-0.5798E-08
71	HFC	-0.2624E 01	-0.2190E 01	-0.1829E 01	-0.1540E 01	-0.1540E 01	-0.1829E 01	-0.2190E 01	-0.2524E 01	-0.2524E 01

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TABLE I. - SUMMARY OF DETAILS FOR PREPARING INPUT DATA CARDS. (See also tables II to IV.)

Card group	Identification	Code symbol	Number of entries	List of entries, sequential order	Card field columns	Format Type	Format Number	Comments and engineering units
1	Composite system card	NL, NPL, NPC, NFPE, NLC	2 to 3 words	Alphabetic characters	1 - 55	55H	4	
2	Data control card		5	N, Pv, N_pc, N_f, N_lC	1 - 25	5(15)	5	
3	Constituent materials elastic properties	Ef11, etc., NUF12, etc., EF12, etc., EM11, etc., NUM12, etc., EM12, etc.	18	E <sub>f11</sub> , E <sub>f22</sub> , E <sub>f33</sub> , ν <sub>f12</sub> , ν <sub>f23</sub> , ν <sub>f13</sub> , G <sub>12</sub> , G <sub>23</sub> , E <sub>m11</sub> , E <sub>m22</sub> , E <sub>m33</sub> , ν <sub>m12</sub> , ν <sub>m23</sub> , ν <sub>m13</sub> , G <sub>m12</sub> , G <sub>m23</sub> , G <sub>m13</sub>	1 - 75	5(E15..8)	35	E, G in psi ν is Poisson's ratio
4	Correlation coefficients for elastic constants, expansion coefficients, and strain magnification factors	VCF(2×10)	20	β <sub>m</sub> , β <sub>m''</sub> , β <sub>m</sub> , β̃ <sub>m</sub> , β <sub>ε</sub> , β <sub>ε''</sub> , β <sub>t</sub> , β <sub>t''</sub> , 0, 0, 0; γ <sub>m</sub> , γ <sub>m''</sub> , γ <sub>m</sub> , γ̃ <sub>m</sub> , γ <sub>ε</sub> , γ <sub>ε''</sub> , γ <sub>t</sub> , γ <sub>t''</sub> , 0, 0, 0, 0	1 - 75	5(E15..8)	35	Ratios evaluated by trial and success
5	Fiber thermal expansion coefficient	VAF(3)	3	α <sub>f11</sub> , α <sub>f22</sub> , α <sub>f33</sub>	1 - 45	5(E15..8)	35	in./in. /°F
6	Matrix thermal expansion coefficient	VAM(3)	3	α <sub>m11</sub> , α <sub>m22</sub> , α <sub>m33</sub>	1 - 45	5(E15..8)	35	in./in. /°F
7	Constituent materials heat conductivities	CHK(3×4)	12	K <sub>f11</sub> , K <sub>f22</sub> , K <sub>f33</sub> , h <sub>cf</sub> , K <sub>mn11</sub> , K <sub>mn22</sub> , K <sub>mn33</sub> , h <sub>cm</sub> , 0, 0, 0, 0, 0, 0, K <sub>v</sub>	1 - 75	5(E15..8)	35	K = $\frac{\text{Btu}}{(\text{hr})(\text{ft}^2)(^{\circ}\text{F}/\text{in.})}$ H <sub>c</sub> = $\frac{\text{Btu}}{(\text{lb})(^{\circ}\text{F})}$
	Heat capacity							
8	Correlation coefficients for heat conductivities	BTA(4)	4	β <sub>kv</sub> , β <sub>k1</sub> , β <sub>k2</sub> , β <sub>k3</sub>	1 - 60	5(E15..8)	35	Ratios evaluated by trial and success
9	Constant π	PIE	1	π-(numerical value)	1 - 15	5(E15..8)	35	Ratio
10	Boolean for thickness	TLINP	1	-----	1 - 6	L6	75	T (true) if ply thickness is input; otherwise F (false)
11	Boolean for membrane and bending symmetry	CSANB	1	-----	1 - 6	L6	75	T (true) if symmetry exists; otherwise F (false)
12	Boolean for interlayer energy contribution	BIDE	1	-----	1 - 6	L6	75	T (true) if contributions are desired; otherwise F (false)

13	Boolean for input displacements	RINDV	1	-----	1 - 6	L6	75	T(true) if displacements are inputs; otherwise F(false)
14	Composite angle, constituents densities, and fiber diameter	THES, RHOF, RHOM, DIAF	4	$\theta_{cs}, \rho_f, \rho_m, d_f$	1 - 60	5(E15.8)	35	$\theta_{cs}$ in degrees (measured from composite structural axes). $\rho$ in lb/in. <sup>3</sup> , $d_f$ in in.
15	Ply void volume ratio	KVL(N <sub>l</sub> )	N <sub>l</sub>	$k_{vl}^i$ i = 1(1)N <sub>l</sub>	1 - 75	5(E15.8)	35	Ratio
16	Ply fiber volume ratio	KFL(N <sub>l</sub> )	N <sub>l</sub>	$k_{fl}^i$ i = 1(1)N <sub>l</sub>	1 - 75	5(E15.8)	35	Ratio
17	Ply orientation angle	THLC(N <sub>l</sub> )	N <sub>l</sub>	$\theta_l^i$ i = 1(1)N <sub>l</sub>	1 - 75	5(E15.8)	35	Degrees measured from composite material axes
18	Ply thickness	TL(N <sub>l</sub> )	N <sub>l</sub>	$t_l^i$ i = 1(1)N <sub>l</sub>	1 - 75	5(E15.8)	35	$t_l$ -inches (values should be read here for both TLINP = T or F
19	Ply temperature difference	PL(50, J)	N <sub>l</sub>	$\Delta T_{\bar{a}}$ i = 1(1)N <sub>l</sub>	1 - 75	5(E15.8)	35	$\Delta T_l$ IN °F
20	Correlation coefficients for strength	BET(2, 8)	20	$\beta_{rr}, \beta_{mr}, \beta_{22r}, \beta_{12s}, \beta_{23s}, \beta_{de}, \beta_{12rt}, \beta_{12tc}, \beta_{fc}, \beta_{mc}, \beta_{22c}, a_1, a_2, 1.0, K_{12ct}, K_{12cc}$	1 - 75	5(E15.8)	35	Ratios (determined by trial and success)
21	Constituents strength properties	SLC	6	$S_{rr}, S_{mc}, \epsilon_{mpr}, \epsilon_{mpc}, \epsilon_{mPS}, \epsilon_{mPOR}$	1 - 75	5(E15.8)	35	S - psi; $\epsilon$ - in./in.
22	Membrane loads	NBS	3N <sub>IC</sub>	$\bar{N}_{cxi}$ j = 1(1)N <sub>IC</sub> $\bar{N}_{cyj}$ j = 1(1)N <sub>IC</sub> $\bar{N}_{cxyj}$ j = 1(1)N <sub>IC</sub>	1 - 75	5(E15.8)	35	lb/in.
23	Moments	MBS	3N <sub>IC</sub>	$\bar{M}_{exxj}$ j = 1(1)N <sub>IC</sub> $\bar{M}_{eyyj}$ j = 1(1)N <sub>IC</sub> $\bar{M}_{exyj}$ j = 1(1)N <sub>IC</sub>	1 - 75	5(E15.8)	35	(lb-in.)/in.
24	Displacements	DISVI	6 per N <sub>IC</sub>	$\epsilon_{csxx}, \epsilon_{csyy}, \epsilon_{csxy}, w_{cbxx}, w_{cbyy}, w_{cbxy}$	1 - 75	5(E15.8)	35	U in in.; W in radians

<sup>a</sup>See fig. 3.

TABLE II. - MULTILAYERED FIBER COMPOSITE ANALYSIS INPUT DATA SAMPLE

THORNEL-50/EPOXY

8	71	54	1420	1
.50000E+08	.10000E+07	.10000E+07	.20000E+00	.25000E+00
.20000E+00	.13000E+07	.70000E+06	.13000E+07	.57000E+06
.57000E+06	.57000E+06	.36000E+00	.36000E+00	.36000E+00
.00000E+00	.00000E+06	.00000E+00		
.40000E+01	.20000E+01	.40000E+01	.20000E+01	.00000E+00
.00000E+00	.00000E+00	.10000E+01	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.10000E+00
.10000E+01	.10000E+01	.00000E+00	.00000E+00	.00000E+00
-.55000E-06	.56000E-05	.56000E-05		
.42800E-04	.42800E-04	.42800E-04		
.58000E+03	.58000E+02	.58000E+02	.17000E+00	.12500E+01
.12500E+01	.12500E+01	.25000E+00	.00000E+00	.00000E+00
.00000E+00	.22500E+00			
.10000E+01	.10000E+01	.10500E+01	.10500E+01	
.31416E+01				

TABLE II. - Continued. MULTILAYERED FIBER COMPOSITE ANALYSIS INPUT DATA SAMPLE

F

F

F

F

. 00000E+00	. 05900E+00	. 04430E+00	. 00026E+00	
. 00000E+00				
. 00000E+00	. 00000E+00	. 00000E+00		
. 50000E+00				
. 50000E+00	. 50000E+00	. 50000E+00		
. 00000E+00	. 45000E+02	- . 45000E+02	. 90000E+02	. 90000E+02
- . 45000E+02	. 45000E+02	. 00000E+00		
. 00805E+00				
. 00805E+00	. 00805E+00	. 00805E+00		
- . 30000E+03				
- . 30000E+03	- . 30000E+03	- . 30000E+03		

TABLE II. - Concluded. MULTILAYERED FIBER COMPOSITE ANALYSIS INPUT DATA SAMPLE

.83000E+00	.10000E+00	.26000E+00	.27000E+00	.17000E+00
.16500E+02	.10000E+01	.10000E+01	.04650E+00	.10000E+01
.50000E+00	.13300E+02	.31900E+05	.10000E+01	.10000E+01
.10000E+01				
.23000E+06	.21500E+05	.02000E+00	.05000E+00	.04500E+00
.04500E+00				
.50000E+04	.00000E+00	.00000E+00		
.10000E+03	.00000E+00	.00000E+00		
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00				

TABLE III. - INPUT DATA FOR BORON/ALUMINUM COMPOSITE

BORON/ALUMINUM					
8	71	54	1	1	
.60000E.08		.60000E.08	.60000E.08	.20000E.00	.20000E.00
.20000E.00		.00000E.00	.00000E.00	.00000E.00	.10000E.08
.10000E.08		.10000E.08	.33000E.00	.33000E.00	.33000E.00
.00000E.00		.00000E.00	.00000E.00		
.40000E.01		.20000E.01	.40000E.01	.20000E.01	.00000E.00
.00000E.00		.00000E.00	.10000E.01	.00000E.00	.00000E.00
.00000E.00		.00000E.00	.00000E.00	.00000E.00	.10000E.01
.10000E.01		.10000E.01	.00000E.00	.00000E.00	.00000E.00
.28000E-05		.28000E-05	.28000E-05		
.12900E-04		.12900E-04	.12900E-04		
.22300E.02		.22300E.02	.22300E.02	.31000E.00	.10040E.04
.10040E.04		.10040E.04	.23000E.00	.00000E.00	.00000E.00
.00000E.00		.22500E.00			
.10000E.01		.10000E.01	.10000E.01	.10000E.01	
.31416E.01					
F					
F					
F					
F					
.00000E.00		.08500E.00	.09800E.00	.00400E.00	
0.00000E.00		0.00000E.00	0.00000E.00	0.00000E.00	0.00000E.00
0.00000E.00		0.00000E.00	0.00000E.00		
0.50000E.00		0.50000E.00	0.50000E.00	0.50000E.00	0.50000E.00
0.50000E.00		0.50000E.00	0.50000E.00		
.00000E.00		.45000E.02	-.45000E.02	.90000E.02	.90000E.02
-.45000E.02		.45000E.02	.00000E.00		
.00500E.00		.00500E.00	.00500E.00	.00500E.00	.00500E.00
.00500E.00		.00500E.00	.00500E.00		
-0.90000E.03		-0.90000E.03	-0.90000E.03	-0.90000E.03	-0.90000E.03
-0.90000E.03		-0.90000E.03	-0.90000E.03		
.56000E.00		.10000E.01	.31300E.00	.46200E.00	.30000E.00
.29200E.01		.10000E.01	.10000E.01	.10000E.01	.10000E.01
.34300E.00		.83300E.01	.52000E.05	.10000E.01	.10000E.01
.10000E.01					
.46000E.06		.52000E.05	.00520E.00	.00520E.00	.00905E.00
.00905E.00					
.50000E.04		.00000E.00	.00000E.00		
.10000E.03		.00000E.00	.00000E.00		
0.00000E.00		0.00000E.00	0.00000E.00	0.00000E.00	0.00000E.00
0.00000E.00					

TABLE IV. - INPUT DATA FOR BORON/EPOXY COMPOSITE

BORON/EPOXY				
8	71	54	1	1
.60000E.08		.60000E.08	.60000E.08	.20000E.00
.20000E.00		.00000E.00	.00000E.00	.56000E.06
.56000E.06		.56000E.06	.35000E.00	.35000E.00
.00000E.00		.00000E.00	.00000E.00	
.40000E.01		.20000E.01	.40000E.01	.20000E.01
.00000E.00		.00000E.00	.10000E.01	.00000E.00
.00000E.00		.00000E.00	.00000E.00	.00000E.00
.10000E.01		.10000E.01	.00000E.00	.00000E.00
.28000E-05		.28000E-05	.28000E-05	
.32000E-04		.32000E-04	.32000E-04	
.22300E.02		.22300E.02	.22300E.02	.31000E.00
.17000E.01		.17000E.01	.25000E.00	.00000E.00
.00000E.00		.22500E.00	.00000E.00	.00000E.00
.10000E.01		.10000E.01	.10000E.01	.10000E.01
.31416E.01				
F				
F				
F				
F				
.00000E.00		.08500E.00	.04400E.00	.00400E.00
.00000E.00		.00000E.00	.00000E.00	.00000E.00
0.00000E.00		0.00000E.00	0.00000E.00	
0.50000E.00		0.50000E.00	0.50000E.00	0.50000E.00
0.50000E.00		0.50000E.00	0.50000E.00	
.00000E.00		.45000E.02	-.45000E.02	.90000E.02
-.45000E.02		.45000E.02	.00000E.00	.90000E.02
.00500E.00		.00500E.00	.00500E.00	.00500E.00
.00500E.00		.00500E.00	.00500E.00	
-0.30000E.03		-0.30000E.03	-0.30000E.03	-0.30000E.03
-0.30000E.03		-0.30000E.03	-0.30000E.03	
.84000E.00		.10000E.01	.90000E.00	.15000E.01
.16500E.02		.10000E.01	.10000E.01	.12000E.00
.12200E.01		.13300E.02	.31900E.05	.10000E.01
.10000E.01				.10000E.01
.46000E.06		.25000E.05	.02700E.00	.07000E.00
.05300E.00				.05300E.00
.50000E.04		.00000E.00	.00000E.00	
.10000E.03		.00000E.00	.00000E.00	
0.00000E.00		0.00000E.00	0.00000E.00	0.00000E.00
0.00000E.00				

TABLE V. - INPUT DATA FOR E-GLASS/EPOXY COMPOSITE

E-GLASS/EPOXY				
8	71	54	204	1
.10600E.08	.10600E.08	.10600E.08	.22000E.00	.22000E.00
.22000E.00	.00000E.00	.00000E.00	.00000E.00	.50000E.06
.50000E.06	.50000E.06	.35000E.00	.35000E.00	.35000E.00
.00000E.00	.00000E.00	.00000E.00		
.40000E.01	.20000E.01	.40000E.01	.20000E.01	.00000E.00
.00000E.00	.00000E.00	.10000E.01	.00000E.00	.00000E.00
.00000E.00	.00000E.00	.00000E.00	.00000E.00	.10000E.01
.10000E.01	.10000E.01	.00000E.00	.00000E.00	.00000E.00
.28000E-05	.28000E-05	.28000E-05		
.32000E-04	.32000E-04	.32000E-04		
.75000E.01	.75000E.01	.75000E.01	.17000E.00	.15000E.01
.15000E.01	.15000E.01	.25000E.00	.00000E.00	.00000E.00
.00000E.00	.22500E.00			
.10000E.01	.10000E.01	.90000E.00	.90000E.00	
.31416E.01				
F				
F				
F				
F				
.00000E.00	.09000E.00	.04000E.00	.36000E-03	
.00000E.00	.00000E.00	.00000E.00	.00000E.00	.00000E.00
0.00000E.00	0.00000E.00	0.00000E.00		
0.50000E.00	0.50000E.00	0.50000E.00	0.50000E.00	0.50000E.00
0.50000E.00	0.50000E.00	0.50000E.00		
-.45000E.02	.45000E.02	.00000E.00		
-.45000E.02	.45000E.02	.00000E.00		
.00800E.00	.00800E.00	.00800E.00	.00800E.00	.00800E.00
.00800E.00	.00800E.00	.00800E.00		
-0.30000E.03	-0.30000E.03	-0.30000E.03	-0.30000E.03	-0.30000E.03
-0.30000E.03	-0.30000E.03	-0.30000E.03	-	
.82000E.00	.10000E.01	.55000E.00	.86000E.00	.82000E.00
.16500E.02	.10000E.01	.10000E.01	.33000E.00	.10000E.01
.11000E.01	.13300E.02	.31900E.05	.10000E.01	.10000E.01
.10000E.01				
.36000E.06	.25000E.05	.02000E.00	.05000E.00	.03500E.00
.03500E.00				
.50000E.04	.00000E.00	.00000E.00		
.10000E.03	.00000E.00	.00000E.00		
0.00000E.00	0.00000E.00	0.00000E.00	0.00000E.00	0.00000E.00
0.00000E.00				

TABLE VI. - INPUT DATA FOR S-GLASS/EPOXY COMPOSITE

S-GLASS/EPOXY					
8	71	54	204	1	
.12400E.08	.12400E.08	.12400E.08	.22000E.00	.22000E.00	
.22000E.00	.00000E.00	.00000E.00	.00000E.00	.50000E.06	
.50000E.06	.50000E.06	.35000E.00	.35000E.00	.35000E.00	
.00000E.00	.00000E.00	.00000E.00			
.40000E.01	.20000E.01	.40000E.01	.20000E.01	.00000E.00	
.00000E.00	.00000E.00	.10000E.01	.00000E.00	.00000E.00	
.00000E.00	.00000E.00	.00000E.00	.00000E.00	.10000E.01	
.10000E.01	.10000E.01	.00000E.00	.00000E.00	.00000E.00	
.28000E-05	.28000E-05	.28000E-05			
.32000E-04	.32000E-04	.32000E-04			
.75000E.01	.75000E.01	.75000E.01	.17000E.00	.17000E.01	
.17000E.01	.17000E.01	.25000E.00	.00000E.00	.00000E.00	
.00000E.00	.22500E.00				
.10000E.01	.10000E.01	.90000E.00	.90000E.00		
.31416E.01					
F					
F					
F					
F					
.00000E.00	.09000E.00	.04000E.00	.36000E-03		
.00000E.00	.00000E.00	.00000E.00	.00000E.00	.00000E.00	
0.00000E.00	0.00000E.00	0.00000E.00			
0.50000E.00	0.50000E.00	0.50000E.00	0.50000E.00	0.50000E.00	
0.50000E.00	0.50000E.00	0.50000E.00			
.00000E.00	.45000E.02	-.45000E.02	.90000E.02	.90000E.02	
-.45000E.02	.45000E.02	.00000E.00			
.01290E.00	.01290E.00	.01290E.00	.01290E.00	.01290E.00	
.01290E.00	.01290E.00	.01290E.00			
-.0.30000E.03	-.0.30000E.03	-.0.30000E.03	-.0.30000E.03	-.0.30000E.03	
-.0.30000E.03	-.0.30000E.03	-.0.30000E.03			
.10000E.01	.10000E.01	.66000E.00	.13000E.01	.11000E.01	
.16500E.02	.10000E.01	.10000E.01	.55000E.00	.10000E.01	
.17000E.01	.13300E.02	.31900E.05	.10000E.01	.10000E.01	
.10000E.01					
.36000E.06	.25000E.05	.02000E.00	.05000E.00	.03500E.00	
.03500E.00					
.50000E.04	.00000E.00	.00000E.00			
.10000E.03	.00000E.00	.00000E.00			
0.00000E.00	0.00000E.00	0.00000E.00			
0.00000E.00					

TABLE VII. - INPUT DATA FOR THORNEL-25/EPOXY COMPOSITE

THORNEL-25/EPOXY

8	71	54	1440	1
.25000E.08	.20000E.07	.20000E.07	.20000E.00	.25000E.00
.20000E.00	.20000E.07	.80000E.06	.20000E.07	.54000E.06
.54600E.06	.54600E.06	.36000E.00	.36000E.00	.36000E.00
.00000E.00	.00000E.00	.00000E.00		
.40000E.01	.20000E.01	.40000E.01	.20000E.01	.10000E.01
.00000E.00	.00000E.00	.10000E.01	.00000E.00	.00000E.00
.00000E.00	.00000E.00	.00000E.00	.00000E.00	.10000E.01
.10000E.01	.10000E.01	.00000E.00	.00000E.00	.00000E.00
-.55000E.06	.56000E.05	.56000E.05		
.42800E.04	.42800E.04	.42000E.04		
.58000E.03	.58000E.02	.58000E.02	.17000E.00	.12500E.01
.12500E.01	.12500E.01	.25000E.00	.00000E.00	.00000E.00
.00000E.00	.22500E.00			
.10000E.01	.10000E.01	.10500E.01	.10500E.01	
	.31415E.01			

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.00000E.00	.05200E.00	.04430E.00	.00029E.00	
.00000E.00	.00000E.00	.00000E.00	.00000E.00	
0.00000E.00	0.00000E.00	0.00000E.00		
0.50000E.00	0.50000E.00	0.50000E.00	0.50000E.00	0.50000E.00
.50000E.00	.50000E.00	.50000E.00		
.00000E.00	.45000E.02	-.45000E.02	.90000E.02	.90000E.02
-.45000E.02	.45000E.02	.00000E.00		
.01300E.00	.01300E.00	.01300E.00	.01300E.02	.01300E.02
.01300E.00	.01300E.00	.01300E.00		
-.0.30000E.03	-.0.30000E.03	-.0.30000E.03	-.0.30000E.03	-.0.30000E.03
-.0.30000E.03	-.0.30000E.03	-.0.30000E.03		
.10000E.01	.10000E.01	.50000E.01	.48000E.00	.38000E.00
.16500E.02	.10000E.01	.10000E.01	.12000E.00	.10000E.01
.49000E.00	.13300E.02	.31900E.05	.10000E.01	.10000E.01
.10000E.01				
.18000E.06	.21000E.05	.02000E.00	.05000E.00	.04500E.00
.04500E.00				
.50000E.04	.00000E.00	.00000E.00		
.10000E.03	.00000E.00	.00000E.00		
0.00000E.00	0.00000E.00	0.00000E.00	0.00000E.00	0.00000E.00
0.00000E.00				

TABLE VIII. - INPUT DATA FOR THORNEL-40/EPOXY COMPOSITE

THORNEL-40/EPOXY				
8	71	54	1440	1
.4000E.08	.1100E.07	.1100E.07	.2000E.00	.2500E.00
.2000E.00	.1500E.07	.8000E.06	.1500E.07	.5000E.06
.5000E.06	.5000E.06	.3500E.00	.3500E.00	.3500E.00
.0000E.00	.0000E.00	.0000E.00	.0000E.00	.0000E.00
.4000E.01	.2000E.01	.4000E.01	.2000E.01	.0000E.00
.0000E.00	.0000E.00	.1000E.01	.0000E.00	.0000E.00
.0000E.00	.0000E.00	.0000E.00	.0000E.00	.1000E.01
.1000E.01	.1000E.01	.0000E.00	.0000E.00	.0000E.00
-.5500E.06	.5600E.05	.5600E.05	.0000E.00	.0000E.00
.4280E.04	.4280E.04	.4280E.04	.0000E.00	.0000E.00
.5800E.03	.5800E.02	.5800E.02	.1700E.00	.1250E.01
.1250E.01	.1250E.01	.2500E.00	.0000E.00	.0000E.00
.0000E.00	.2250E.00	.0000E.00	.0000E.00	.0000E.00
.1000E.01	.1000E.01	.1050E.01	.1050E.01	.1050E.01
.31416E.01				
F				
F				
F				
F				
.0000E.00	.0560E.00	.04430E.00	.00027E.00	
.0000E.00	.0000E.00	.0000E.00	.0000E.00	.0000E.00
0.0000E.00	0.0000E.00	0.0000E.00	0.0000E.00	.0000E.00
0.5000E.00	0.5000E.00	0.5000E.00	0.5000E.00	0.5000E.00
0.5000E.00	0.5000E.00	0.5000E.00	0.5000E.00	0.5000E.00
.0000E.00	.4500E.02	-.4500E.02	.9000E.02	.9000E.02
-.4500E.02	.4500E.02	.0000E.00	.0000E.00	
.0090E.00	.0090E.00	.0090E.00	.0090E.00	.0090E.00
.0090E.00	.0090E.00	.0090E.00	.0090E.00	.0090E.00
-0.3000E.03	-0.3000E.03	-0.3000E.03	-0.3000E.03	-0.3000E.03
-0.3000E.03	-0.3000E.03	-0.3000E.03	-0.3000E.03	-0.3000E.03
.8400E.00	.1000E.01	.0850E.00	.4600E.00	.2700E.00
.1650E.02	.1000E.01	.1000E.01	.0800E.00	.1000E.01
.5000E.00	.1330E.02	.3190E.05	.1000E.01	.1000E.01
.1000E.01				
.2500E.06	.2100E.05	.0200E.00	.0500E.00	.0450E.00
.0450E.00				
.5000E.04	.0000E.00	.0000E.00	.0000E.00	
.1000E.03	.0000E.00	.0000E.00	.0000E.00	
0.0000E.00	0.0000E.00	0.0000E.00	0.0000E.00	0.0000E.00
0.0000E.00				

TABLE IX. - INPUT DATA FOR THORNEL-50/EPOXY COMPOSITE

THORNEL-50/EPOXY

8	71	54	1420	1
.50000E.08		.10000E.07	.10000E.07	.20000E.00
.20000E.00		.13000E.07	.70000E.06	.13000E.07
.57000E.06		.57000E.06	.36000E.00	.36000E.00
.00000E.00		.00000E.00	.00000E.00	
.40000E.01		.20000E.01	.40000E.01	.20000E.01
.00000E.00		.00000E.00	.23560E.01	.00000E.00
.00000E.00		.00000E.00	.00000E.00	.10000E.01
.10000E.01		.10000E.01	.00000E.00	.00000E.00
-.55000E.06		.56000E.05	.56000E.05	
.42800E.04		.42800E.04	.42800E.04	
.58000E.03		.58000E.02	.58000E.02	.17000E.00
.12500E.01		.12500E.01	.25000E.00	.00000E.00
.00000E.00		.22500E.00		
.10000E.01		.10000E.01	.10500E.01	.10500E.01
.31416E.01				

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.00000E.00	.05900E.00	.04430E.00	.00026E.00	
.00000E.00	.00000E.00	.00000E.00	.00000E.00	.00000E.00
0.00000E.00	0.00000E.00	0.00000E.00		
0.50000E.00	0.50000E.00	0.50000E.00	0.50000E.00	0.50000E.00
0.50000E.00	0.50000E.00	0.50000E.00		
.00000E.00	.45000E.02	-.45000E.02	.90000E.02	.90000E.02
-.45000E.02	.45000E.02	.00000E.00		
.00805E.00	.00805E.00	.00800E.00	.00800E.00	.00800E.00
.00805E.00	.00805E.00	.00800E.00		
-0.30000E.03	-0.30000E.03	-0.30000E.03	-0.30000E.03	-0.30000E.03
-0.30000E.03	-0.30000E.03	-0.30000E.03		
.83000E.00	.10000E.01	.26000E.00	.27000E.00	.17000E.00
.16500E.02	.10000E.01	.10000E.01	.04650E.00	.10000E.01
.50000E.00	.13300E.02	.31900E.05	.10000E.01	.10000E.01
.10000E.01				
.23000E.06	.21000E.05	.02000E.00	.05000E.00	.04500E.00
.04500E.00				
.50000E.04	.00000E.00	.00000E.00		
.10000E.03	.00000E.00	.00000E.00		
0.00000E.00	0.00000E.00	0.00000E.00	0.00000E.00	0.00000E.00
0.00000E.00				

TABLE X. - INPUT DATA FOR MODMOR-I/EPOXY COMPOSITE

MODMOR-I/EPOXY					
8	71	5410000	1		
.60000E.08	.09000E.07	.09000E.07	.20000E.00	.25000E.00	
.20000E.00	.11000E.07	.70000E.06	.11000E.07	.50000E.06	
.50000E.06	.50000E.06	.35000E.00	.35000E.00	.35000E.00	
.00000E.00	.00000E.00	.00000E.00			
.40000E.01	.20000E.01	.40000E.01	.20000E.01	.00000E.00	
.00000E.00	.00000E.00	.10000E.01	.00000E.00	.00000E.00	
.00000E.00	.00000E.00	.00000E.00	.00000E.00	.10000E.01	
.10000E.01	.10000E.01	.00000E.00	.00000E.00	.00000E.00	
-.55000E.-06	.56000E.-05	.56000E.-05			
.42800E.-04	.42800E.-04	.42800E.-04			
.58000E.03	.58000E.02	.58000E.02	.17000E.00	.12500E.01	
.12500E.01	.12500E.01	.25000E.00	.00000E.00	.00000E.00	
.00000E.00	.22500E.00				
.10000E.01	.10000E.01	.10500E.01	.10500E.01		
.31416E.01					
F					
F					
F					
F					
.00000E.00	.07200E.00	.04430E.00	.00030E.00		
.00000E.00	.00000E.00	.00000E.00	.00000E.00	.00000E.00	
0.00000E.00	0.00000E.00	0.00000E.00			
0.50000E.00	0.50000E.00	0.50000E.00	0.50000E.00	0.50000E.00	
0.50000E.00	0.50000E.00	0.50000E.00			
.00000E.00	.45000E.02	-.45000E.02	.90000E.02	.90000E.02	
-.45000E.02	.45000E.02	.00000E.00			
.01190E.00	.01190E.00	.01190E.00	.01190E.00	.01190E.00	
.01190E.00	.01190E.00	.01190E.00			
-.03000E.03	-.03000E.03	-.03000E.03	-.03000E.03	-.03000E.03	
-.03000E.03	-.03000E.03	-.03000E.03			
.10000E.01	.10000E.01	.50000E.00	.91000E.00	.50000E.00	
.16500E.02	.10000E.01	.10000E.01	.09200E.00	.10000E.01	
.65000E.00	.13300E.02	.31900E.05	.10000E.01	.10000E.01	
.10000E.01					
.25000E.06	.21000E.05	.02000E.00	.05000E.00	.04500E.00	
.04500E.00					
.50000E.04	.00000E.00	.00000E.00			
.10000E.03	.00000E.00	.00000E.00			
0.00000E.00	0.00000E.00	0.00000E.00	0.00000E.00	0.00000E.00	
0.00000E.00					

TABLE XI. - INPUT DATA FOR MODMOR-II/EPOXY COMPOSITE

MODMOR-II/EPOXY

8	71	5410000	1	
.38000E+08	.11000E+07	.11000E+07	.20000E+00	.25000E+00
.20000E+00	.15000E+07	.80000E+06	.15000E+07	.50000E+06
.50000E+06	.50000E+06	.35000E+00	.35000E+00	.35000E+00
.00000E+00	.00000E+00	.00000E+00		
.40000E+01	.20000E+01	.40000E+01	.20000E+01	.00000E+00
.00000E+00	.00000E+00	.10000E+01	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.10000E+01
.10000E+01	.10000E+01	.00000E+00	.00000E+00	.00000E+00
-.55000E-06	.56000E-05	.56000E-05		
.42800E-04	.42800E-04	.42800E-04		
.58000E+03	.58000E+02	.58000E+02	.17000E+00	.12500E+01
.12500E+01	.12500E+01	.25000E+00	.00000E+00	.00000E+00
.00000E+00	.22500E+00			
.10000E+01	.10000E+01	.10500E+01	.10500E+01	
.31416E+01				
.00000E+00	.06300E+00	.04430E+00	.00030E+00	
F				
F				
F				
F				
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00		
0.50000E+00	0.50000E+00	0.50000E+00	0.50000E+00	0.50000E+00
0.50000E+00	0.50000E+00	0.50000E+00		
.00000E+00	.45000E+02	-.45000E+02	.90000E+02	.90000E+02
-.45000E+02	.45000E+02	.00000E+00		
.01190E+00	.01190E+00	.01190E+00	.01190E+00	.01190E+00
.01190E+00	.01190E+00	.01190E+00		
-0.30000E+03	-0.30000E+03	-0.30000E+03	-0.30000E+03	-0.30000E+03
-0.30000E+03	-0.30000E+03	-0.30000E+03		
.84000E+00	.10000E+01	.70000E+00	.13700E+01	.80000E+00
.16500E+02	.10000E+01	.10000E+01	.16000E+00	.10000E+01
.70000E+00	.13300E+02	.31900E+05	.10000E+01	.10000E+01
.10000E+01				
.35000E+06	.21000E+05	.02000E+00	.05000E+00	.04500E+00
.04500E+00				
.50000E+04	.00000E+00	.00000E+00		
.10000E+03	.00000E+00	.00000E+00		
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00				

TABLE XII. - INPUT DATA FOR BERYLLIUM/EPOXY COMPOSITE

BERYLLIUM/EPOXY

8	71	54	1	1
.44000E.08		.44000E.08	.44000E.08	.10000E.00
.10000E.00		.00000E.00	.00000E.00	.00000E.00
.52000E.06		.52000E.06	.35000E.00	.52000E.06
.00000E.00		.00000E.00	.00000E.00	.35000E.00
.40000E.01		.20000E.01	.40000E.01	.20000E.01
.00000E.00		.00000E.00	.10000E.01	.00000E.00
.00000E.00		.00000E.00	.00000E.00	.00000E.01
.10000E.01		.10000E.01	.00000E.00	.10000E.01
.64000E-05		.64000E-05	.64000E-05	.00000E.00
.32000E-04		.32000E-04	.32000E-04	.00000E.00
.10440E.04		.10440E.04	.10440E.04	.45000E.00
.17000E.01		.17000E.01	.25000E.00	.00000E.00
.00000E.00		.22500E.00		.00000E.00
.10000E.01		.10000E.01	.10000E.01	.10000E.01
.31416E.01				

F

F

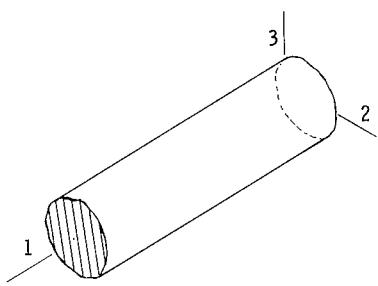
F

F

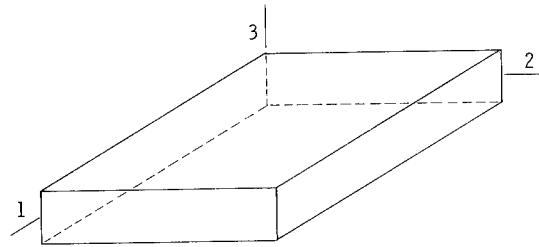
.00000E.00		.05700E.00	.04400E.00	.00500E.00
.00000E.00		.00000E.00	.00000E.00	.00000E.00
0.00000E.00		0.00000E.00	0.00000E.00	
0.50000E.00		0.50000E.00	0.50000E.00	0.50000E.00
0.50000E.00		0.50000E.00	0.50000E.00	0.50000E.00
.00000E.00		.45000E.02	-.45000E.02	.90000E.02
-.45000E.02		.45000E.02	.00000E.00	.90000E.02
.00500E.00		.00500E.00	.00500E.00	.00500E.00
.00500E.00		.00500E.00	.00500E.00	.00500E.00
-0.30000E.03		-0.30000E.03	-0.30000E.03	-0.30000E.03
-0.30000E.03		-0.30000E.03	-0.30000E.03	-0.30000E.03
.10000E.01		.10000E.01	.53000E.00	.14000E.01
.16500E.02		.10000E.01	.10000E.01	.05200E.00
.90000E.00		.13300E.02	.31900E.05	.10000E.01
.10000E.01				.10000E.01
.13300E.06		.25000E.05	.02700E.00	.07000E.00
.05300E.00				.05300E.00
.50000E.04		.00000E.00	.00000E.00	
.10000E.03		.00000E.00	.00000E.00	
0.00000E.00		0.00000E.00	0.00000E.00	0.00000E.00
0.00000E.00				

TABLE XIII. - INPUT-OUTPUT FORMAT IDENTIFICATION FOR INPUT DATA

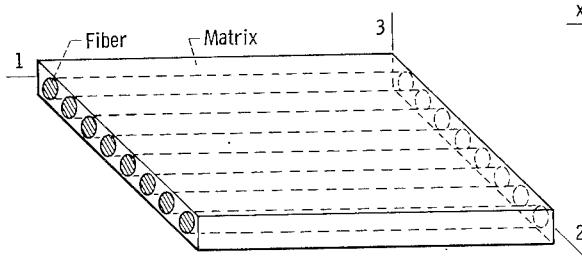
Card first entry	Format statement number (see compiled listing)			Comments
	Output heading	Read	Write	
THORNEL 50/EPOXY	---	4	4	Composite system
NL	11	5	10	Integers
EF11	70	35	37	Fiber and matrix elastic constants are read in one statement
EM11				
VCF	41	35	37	Correlation coefficients for thermoelastic
VAF	40	35	37	Fiber thermal coefficients of expansion
VAM	45	35	37	Matrix thermal coefficients of expansion
CHK	55	35	37	Constituent heat conductivities and capacities
BTA	60	35	37	Correlation coefficients for conductivities
PIE	65	35	37	Constant $\pi$
TLINP	80	75	75	Boolean for thickness
CSANB	85	75	75	Boolean for bending symmetry
BIDE	87	75	75	Boolean for interply layer effects
RINDV	88	75	75	Boolean for load conditions
THCS	90	35	37	Load angle, densities, equivalent fiber diameter
KVL	95	35	37	Ply void content
KFL	100	35	37	Ply fiber content
THCL	105	35	37	Ply orientation angle
TL	110	35	37	Ply thickness
PTEMP	111	35	37	Ply temperature
BET	115	35	37	Adjustment factors for limit conditions
LSC	120	35	37	Limit conditions - stress, strain
NBS	130	35	37	Load conditions - membrane forces
MBS	131	35	37	Load conditions - bending moments
DISV1	132	35	37	Displacements



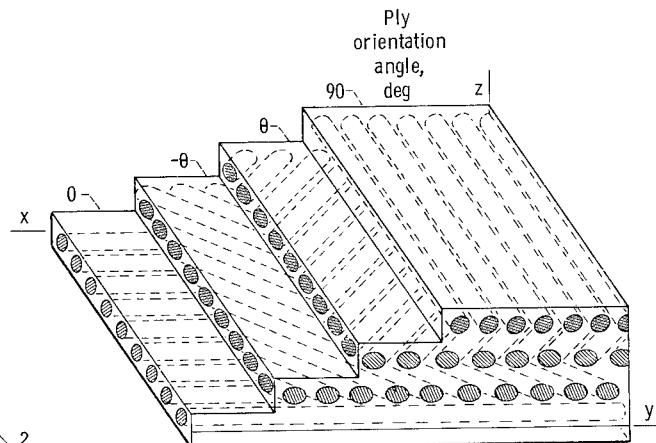
(a) Fiber. Properties needed:  $E_{f11}, 22, 33;$   
 $\nu_{f12, 23, 13}; G_{f12, 23, 13}; \alpha_{f11, 22, 33};$   
 $K_{f11, 22, 33}; H_{cf}, \rho_f, N_f; d_f; S_{ft};$



(b) Matrix. Properties needed:  $E_{m11}, 22, 33;$   
 $\nu_{m12, 23, 13}; G_{f12, 23, 13}; \alpha_{m11, 22, 33};$   
 $K_{m11, 22, 33}; H_{cm}, \rho_m, S_{mc}, \epsilon_{mp}, \epsilon_{mpc},$   
 $\epsilon_{mps}, \epsilon_{mpTOR};$



(c) Ply. Input: Fiber and matrix properties:  $\beta_0, \beta_h, \beta_s,$   
 $\Delta T.$  Properties computed:  $E_{l11, 22, 33}; \nu_{l12, 23, 13};$   
 $G_{l12, 23, 13}; \alpha_{l11, 22, 33}; K_{l11, 22, 33}; H_{cl}, \rho_l, t_l, \delta_l;$   
 $S_{l11T, 11C, 22T, 22C, 12S, 23S}; K_{l12}.$  Stress analysis:  
 $\epsilon_{l11, 22, 12}; \sigma_{l11, 22, 12} = 1.0 - F(\sigma, S, K_{l12}).$



(d) Composite. Input: Ply properties;  $\theta_l;$   $H_l;$   $K_{l12}\alpha\beta;$   $\bar{N}_{cx}, \bar{M}_{cx}$  or  
 $U_{cx}, W_{cx}.$  Output:  $\{\epsilon_{cx}\} = [E_c]\{\sigma_c\} + \Delta T\{\alpha_c\}; [E_c]^{-1}, K_{cxx}, y, xy, xz, H_c,$   
 $\{\bar{N}_{cx}\} = [A_{cx} C_{cx}] \{U_{cx}\} + \{N_{cx}\Delta T\}$  and the inverse,  $\Delta\varphi_{delj}.$

Figure 1. - Typical multilayered fiber composite and some basic definitions.

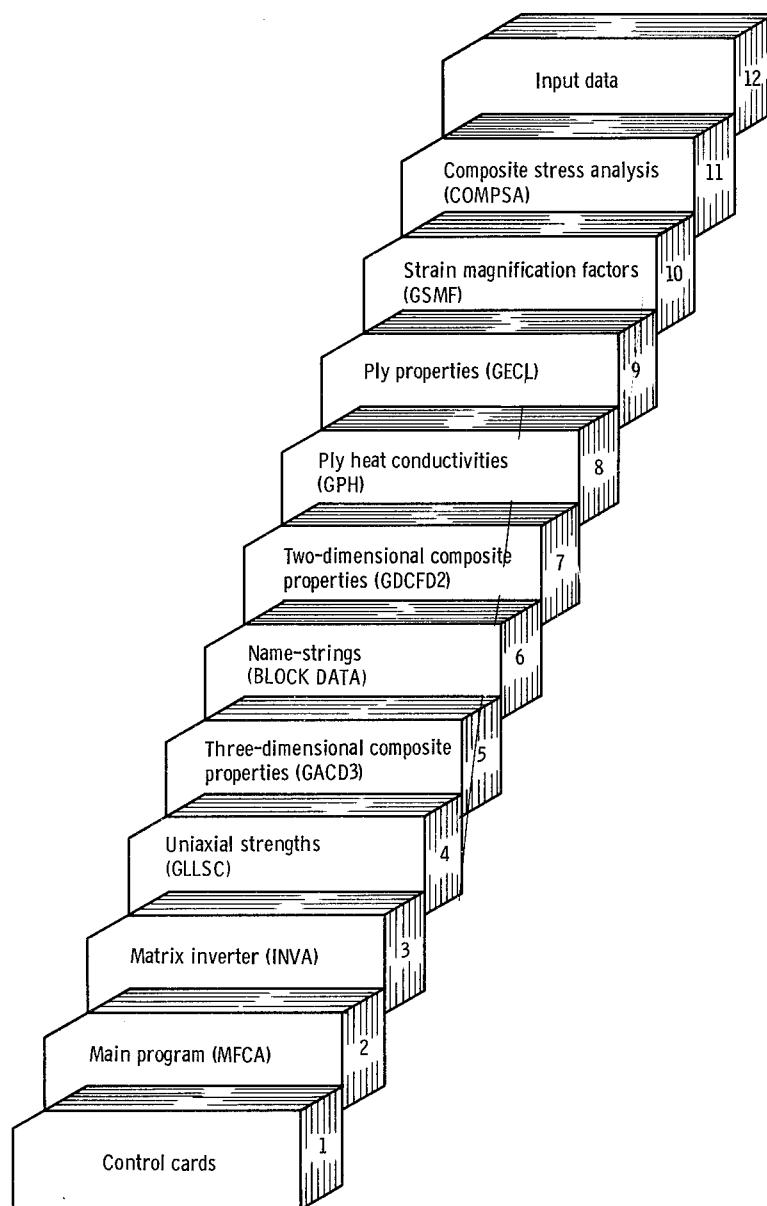


Figure 2. - Code physical arrangement.

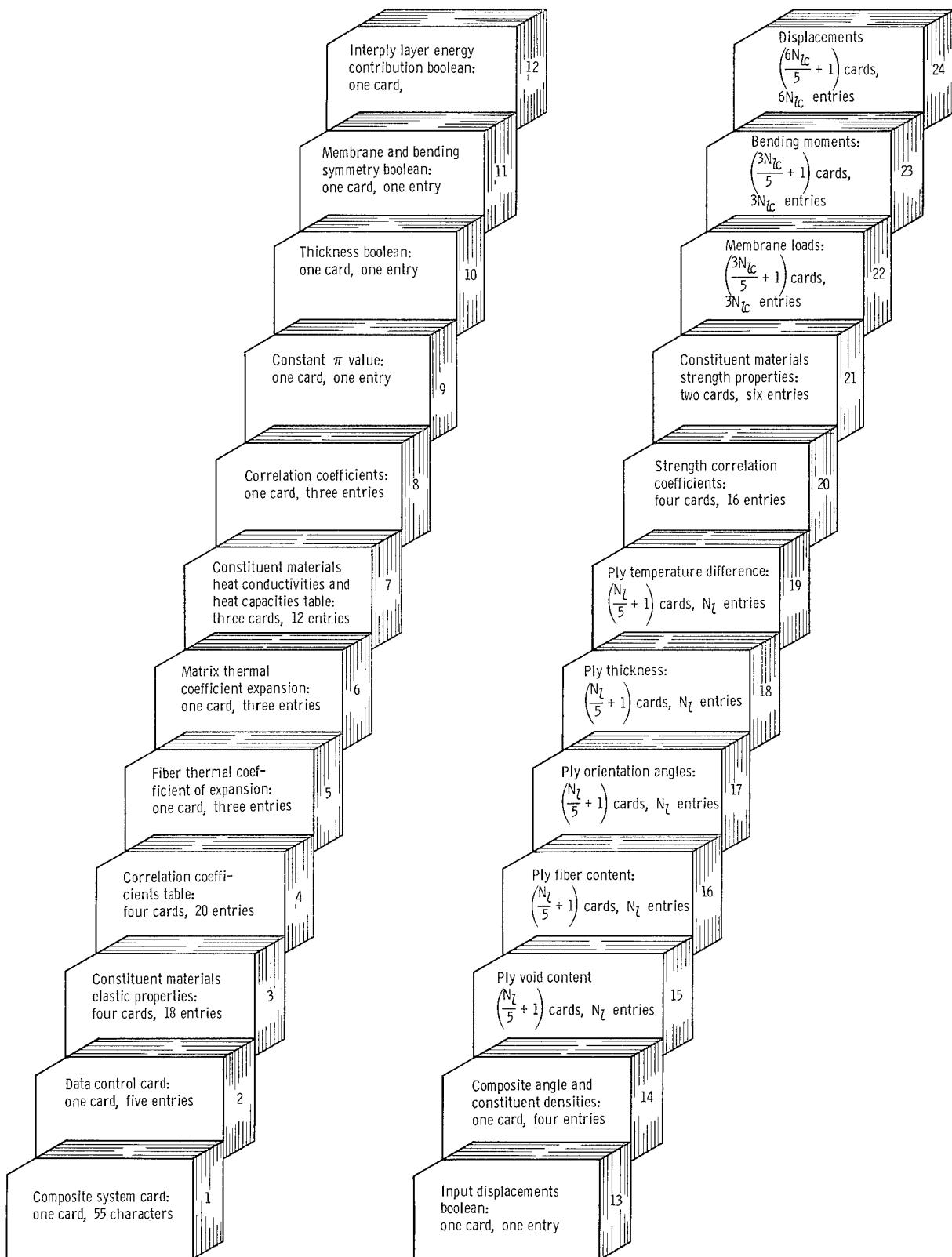


Figure 3. - Physical arrangement of input data cards.

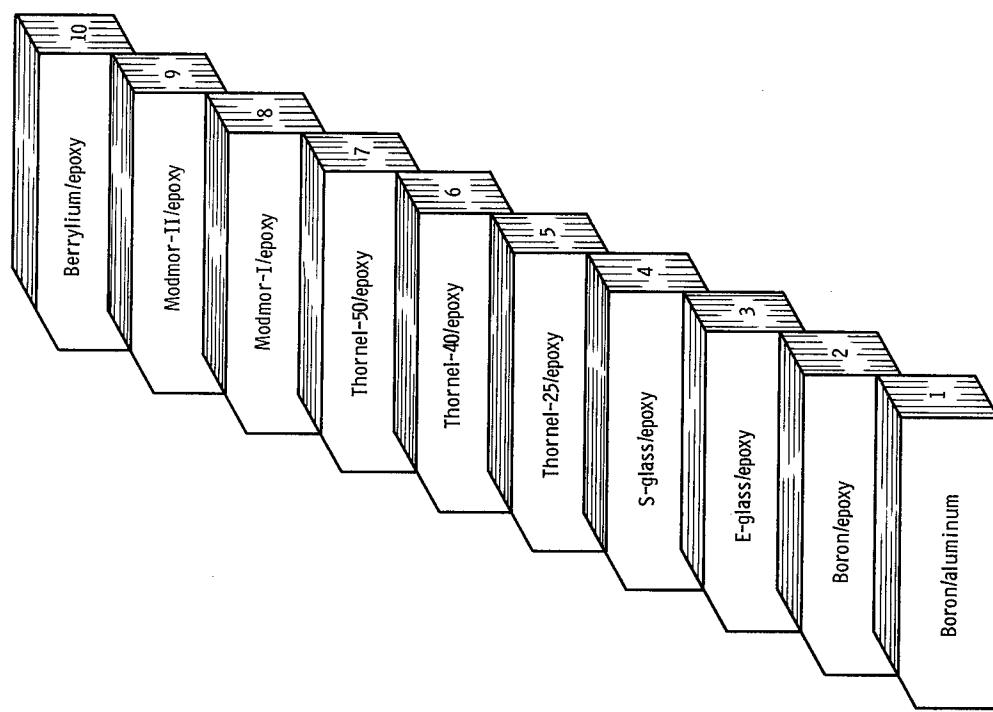


Figure 4. - Composite systems for which input data are supplied.

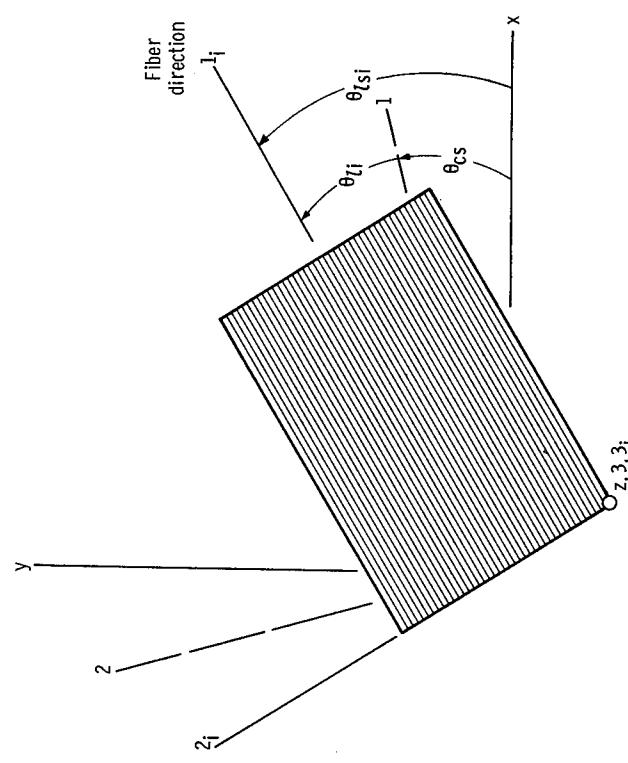


Figure 5. - Ply orientation geometry. Composite structural axes,  $x, y, z$ ; composite material axes,  $1, 2, 3$ ; ply material axes (coincides with fiber direction,  $1_i, 2_i, 3_i$ ).

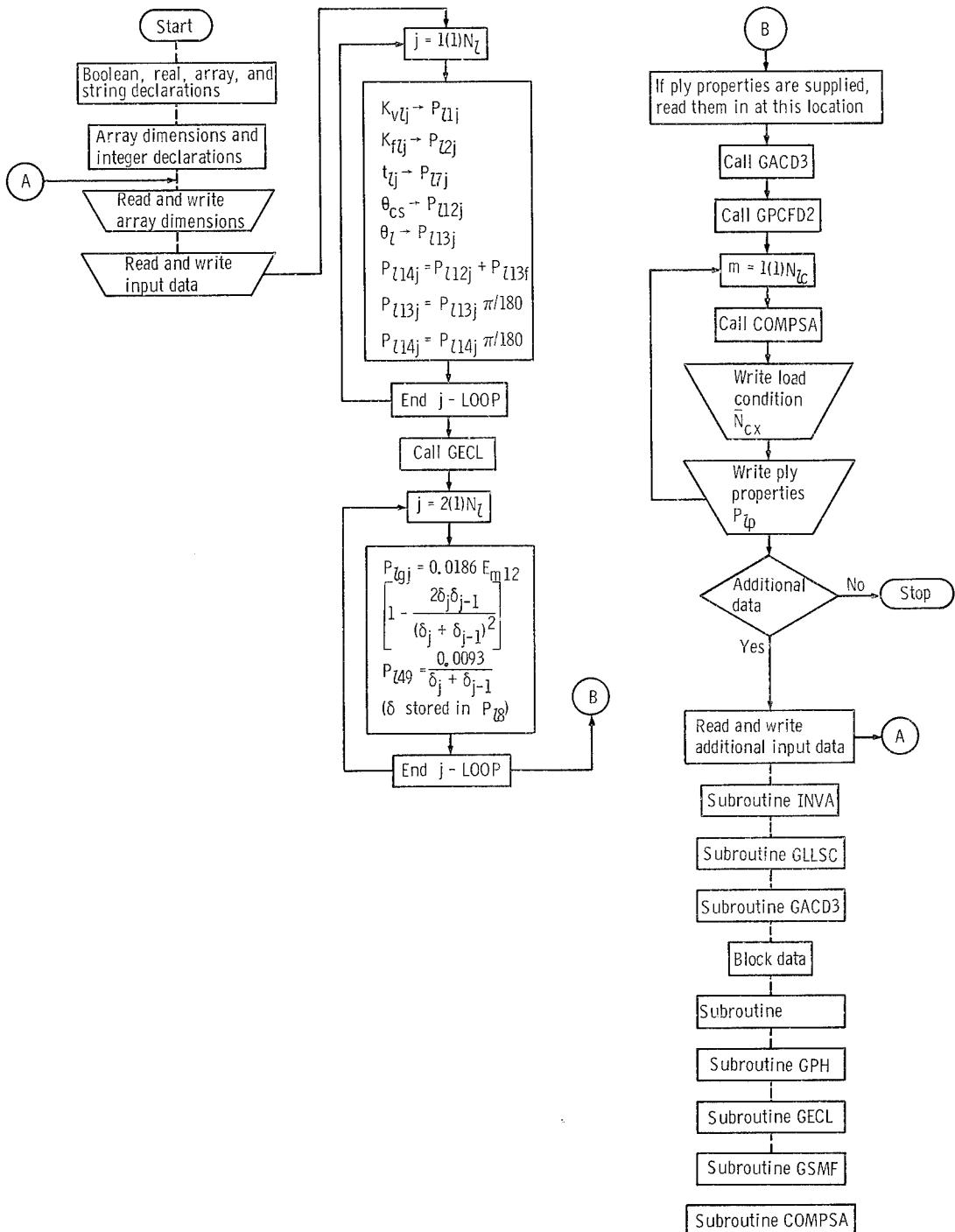


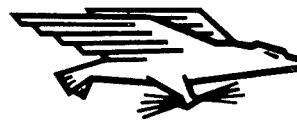
Figure 6. - Code MAIN PROGRAM flow chart.

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